



# Surface changes of metal alloys and high-strength ceramics after ultrasonic scaling and intraoral polishing

Hyung-In Yoon<sup>1</sup>, Hyo-Mi Noh<sup>2</sup>, Eun-Jin Park<sup>3\*</sup>

<sup>1</sup>Department of Prosthodontics, School of Dentistry, Seoul National University, Seoul, Republic of Korea

<sup>2</sup>Department of Clinical Oral Health Science Graduate School of Clinical Dentistry, Ewha Womans University, Seoul, Republic of Korea

<sup>3</sup>Department of Dentistry, School of Medicine, Ewha Womans University, Seoul, Republic of Korea

**PURPOSE.** This study was to evaluate the effect of repeated ultrasonic scaling and surface polishing with intraoral polishing kits on the surface roughness of three different restorative materials. **MATERIALS AND METHODS.** A total of 15 identical discs were fabricated with three different materials. The ultrasonic scaling was conducted for 20 seconds on the test surfaces. Subsequently, a multi-step polishing with recommended intraoral polishing kit was performed for 30 seconds. The 3D profiler and scanning electron microscopy were used to investigate surface integrity before scaling (pristine), after scaling, and after surface polishing for each material. Non-parametric Friedman and Wilcoxon signed rank sum tests were employed to statistically evaluate surface roughness changes of the pristine, scaled, and polished specimens. The level of significance was set at 0.05. **RESULTS.** Surface roughness values before scaling (pristine), after scaling, and polishing of the metal alloys were  $3.02 \pm 0.34 \mu\text{m}$ ,  $2.44 \pm 0.72 \mu\text{m}$ , and  $3.49 \pm 0.72 \mu\text{m}$ , respectively. Surface roughness of lithium disilicate increased from  $2.35 \pm 1.05 \mu\text{m}$  (pristine) to  $28.54 \pm 9.64 \mu\text{m}$  (scaling), and further increased after polishing ( $56.66 \pm 9.12 \mu\text{m}$ ,  $P < .05$ ). The zirconia showed the most increase in roughness after scaling (from  $1.65 \pm 0.42 \mu\text{m}$  to  $101.37 \pm 18.75 \mu\text{m}$ ), while its surface roughness decreased after polishing ( $29.57 \pm 18.86 \mu\text{m}$ ,  $P < .05$ ). **CONCLUSION.** Ultrasonic scaling significantly changed the surface integrities of lithium disilicate and zirconia. Surface polishing with multi-step intraoral kit after repeated scaling was only effective for the zirconia, while it was not for lithium disilicate. [*J Adv Prosthodont 2017;9:188-94*]

**KEYWORDS:** Surface roughness; Restorative materials; Ultrasonic scaling; Polishing

## INTRODUCTION

In general, dental caries and periodontal disease are known to be caused by dental plaque accumulation.<sup>1</sup> To maintain a favorable oral health condition, it is essential to manage dental plaque by periodical oral examinations and intraoral

scaling.<sup>2,3</sup> Scaling treatment removes dental plaque or calculus accumulated on the surfaces of teeth or restorations, resulting in the clean surfaces with low surface energy.<sup>4</sup> The scaling is mainly conducted with either an ultrasonic scaler or a periodontal curette.<sup>5-7</sup> However, the smooth surfaces of restorations are sometimes roughened by the use of an ultrasonic scaler,<sup>8-10</sup> which possibly increase the formation of microorganism colonies and the buildup of dental plaque.<sup>11,12</sup> The roughened surfaces of restorations may cause the formation of a biofilm, the propagation of bacteria, and surface discoloration.<sup>13-15</sup> To minimize the changes in surface roughness of the restorative materials within the oral cavity, careful polishing after scaling may be required.<sup>16-18</sup>

A porcelain-fused-to-metal (PFM) has been used as a gold standard for the esthetic restoration of the anterior region.<sup>19</sup> In addition, various ceramic materials were developed and clinically applied to replace conventional metal framework for natural appearance. However, ceramic mate-

Corresponding author:  
Eun-Jin Park  
Department of Dentistry, School of Medicine, Ewha Womans University  
1071, Anyangcheon-ro, Yangcheon-gu, Seoul 07985, Republic of Korea  
Tel. +82226505042; e-mail, prosth@ewha.ac.kr  
Received August 24, 2016 / Last Revision December 12, 2016 / Accepted  
January 10, 2017

© 2017 The Korean Academy of Prosthodontics  
This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

rial has a major drawback of fracture and fatigue.<sup>20,21</sup> With the advances in the computer-aided design/computer-aided manufacturing (CAD/CAM) technology, use of high-strength polycrystalline ceramics such as lithium disilicate or partially-stabilized tetragonal zirconia has been increased in clinical dentistry.<sup>22-24</sup> Especially, zirconia shows excellent mechanical strength and biocompatibility, and low plaque accumulation and bacterial adhesion.<sup>25</sup> For the long-term stability of restoration, inherent surface characteristics of metal and ceramic materials should be considered during the periodic oral health maintenance, including ultrasonic scaling.

To the best of our knowledge, there were studies on the effects of scaling on restorative materials or on the changes in surface roughness in relation to scaling methods, few studies have been reported about the surface changes by repeated ultrasonic scaling and subsequent intraoral polishing.<sup>26,27</sup> Therefore, the aim of this study was to evaluate the surface roughness changes in three different restorative materials (nickel-chromium alloy, lithium disilicate glass ceramic, and zirconia) after repeated treatment with an ultrasonic scaler and subsequent polishing with intraoral polishing systems. The null hypothesis was that there would be no difference in surface roughness of restorative materials according to the materials and in each of the three treatment steps (before scaling, after repeated scaling, and surface polishing).

## MATERIALS AND METHODS

Two representative ceramics for esthetic restoration, lithium disilicate glass ceramic and partially stabilized tetragonal zirconia, were used for this *in-vitro* pilot study. A base metal alloy was used as a control. The chemical composition and manufacturers' information of the tested materials are summarized in Table 1. A total of 15 identical discs with a diameter of 15 mm and a thickness of 1.5 mm were prepared. For the lithium disilicate group, the disc specimen was produced by pressing glass ceramic ingot (IPS e.max

press HT A2, Ivoclar Vivadent, Schaan, Liechtenstein) into the mold using a furnace (Propress100, Whip Mix Corp., Louisville, KY, USA) according to the manufacturer's instruction. To simulate clinically-relevant finishing process for esthetic restorations, one circular testing surface of each disc was subsequently glazed (IPS e.max ceram Glaze Paste, Ivoclar Vivadent). For the zirconia group, 3 mol% yttria-stabilized tetragonal zirconia polycrystal blocks (LUXEN Smile, Dentalmax, Seoul, Korea) were milled into the disc shapes and sintered at 1500°C for 3 hours. Similar to the lithium disilicate group, one testing surface of each disc was glazed according to the manufacturer's recommendation (Vita Akzent, VITA, Bad Säckingen, Germany). For the metal alloy control group, a nickel-chromium alloy (VeraBond 2V, Aalbadent, Hague, Netherlands) was used to cast disc-shaped specimens of the same test dimension with other ceramic groups. A testing surface of each metal disc was carefully polished with a laboratory silicon mounted polishing kit (Brownie and Greenie polishers, SHOFU, Kyoto, Japan) and low-speed hand-piece.

A 5 mm × 5 mm area on the testing surface of each disc was designated for the scaling treatment. An ultrasonic scaler (Piezon, EMS, Nyon, Switzerland) with stainless steel tip (P type) was used with sufficient cooling water. A single operator with more than 10 years of clinical experience conducted the scaling treatment to standardize the treatment procedure. The scaling was conducted for 20 seconds in a reciprocal motion, repeated 10 times within the designated area. The angle between the surface of each disc and the scaler tip was maintained at 0°, according to the protocols of previous study.<sup>10</sup>

After the scaling process, surface polishing of each prepared disc was conducted with a material-specific intraoral polishing system. A silicon polishing kit for metal alloy (Brownie/Greenie silicon polishers, SHOFU), a 3-step polishing kit for glass ceramic (OpraFine, Ivoclar Vivadent), and a 2-step polishing kit for zirconia ceramic (DIACERA, EVE, Pforzheim, Germany) were used to polish roughened surfaces of the nickel-chromium alloy disc, lithium disilicate

**Table 1.** Chemical components of three restorative materials tested in this study

Nickel-Chromium alloy		Lithium disilicate		Zirconia (3Y-TZP)	
Element	Percent (%)	Element	Percent (%)	Element	Percent (%)
Ni	71.8	SiO <sub>2</sub>	58 - 80	ZrO <sub>2</sub>	80 - 96
Cr	12.8	Li <sub>2</sub> O	11 - 19	HfO <sub>2</sub>	< 5
Mo	9.0	K <sub>2</sub> O	0 - 13	Y <sub>2</sub> O <sub>3</sub>	4 - 10
Nb	4.0	P <sub>2</sub> O <sub>5</sub>	0 - 11	Er <sub>2</sub> O <sub>3</sub>	< 0.1
Al	2.5	ZrO <sub>2</sub>	0 - 8		
Si	< 0.1	ZnO	0 - 8		
Ti	< 0.1				

glass ceramic disc, and the zirconia disc, respectively. The same operator who conducted the scaling treatment performed the polishing procedures for a standardized process. Based on the protocols of previous studies,<sup>28-31</sup> the operator applied uniform finger pressure during polishing, in one direction for 30 seconds of identical application time. The rotation rate for each specimen was set according to the step-by-step guideline of each polishing system.

To evaluate the surface morphology of each specimen at each treatment step, a three-dimensional surface measurement apparatus (3D optical profiler, Wyko NT1100, Veeco, Plainview, NY, USA) based on white light vertical scanning interferometry was used to measure the surface roughness values (Ra). The Ra value is the average absolute deviation of the roughness irregularities from the mean line over one sampling length. Surface roughness measurement was conducted using a contactless method, and the dimensions of the image and the vertical measurement range were set to 600 μm × 456 μm and 0 - 1000 μm, respectively. The surface condition of prepared testing disc before scaling (pristine step) was analyzed with a scanning electron microscopy (SEM, S-4800, HITACHI, Tokyo, Japan) under 3 kV accelerating voltage and magnification at ×500. Changes in the surface morphology of each test specimen after repeated scaling and surface polishing with intraoral kit were also microscopically investigated.

Using non-parametric statistical analysis, the Friedman

test was used to examine changes in the surface roughness within each test specimen after three different treatment steps (pristine, after repeated scaling, and after surface polishing). The Wilcoxon signed rank sum test was used for post-hoc analysis. To compare the surface roughness among three different restorative materials at each treatment step (pristine, after scaling, and after polishing), the Kruskal-Wallis test was used. The statistics program (SPSS 22.0, IBM SPSS statistic, Chicago, IL, USA) was used with the statistical significance set to 0.05.

**RESULTS**

The means and standard deviations of the surface roughness values (Ra, in μm) for all the specimens at three different surface treatment conditions (initial before scaling, after repeated scaling, and after surface polishing using intraoral polishing kits) were summarized in Table 2. The surface roughness values for the nickel-chromium alloy were similar irrespective of the surface treatment steps (*P* = .165). On the other hand, the lithium disilicate and zirconia discs showed significant changes in surface roughness values after the treatments (both *P* < .05). The post-hoc analysis revealed that the changes were statistically significant between before (pristine) and after repeated scaling, as well as after repeated scaling and surface polishing with intraoral polishing kits (*P* < .05).

**Table 2.** Changes of surface roughness (Ra) values of three different restorative materials before scaling (pristine), after scaling, and after surface polishing

	N	Pristine Average (SD)	Scaling Average (SD)	Surface polishing Average (SD)	<i>P</i> value
Metal alloy	5	3.02 (± 0.34)	2.44 (± 0.72)	3.49 (± 0.72)	.165
Lithium disilicate	5	2.35 (± 1.05) <sup>a</sup>	28.54 (± 9.64) <sup>b</sup>	56.66 (± 9.12) <sup>c</sup>	.007*
Zirconium dioxide	5	1.65 (± 0.42) <sup>a</sup>	101.37 (± 18.75) <sup>b</sup>	29.57 (± 18.86) <sup>c</sup>	.007*

The different lower case letters <sup>a, b, c</sup> indicate significant statistical differences. *P* < .05.

**Table 3.** Surface roughness (Ra) values of three different restorative materials at each treatment step; pristine, after scaling, and after surface polishing

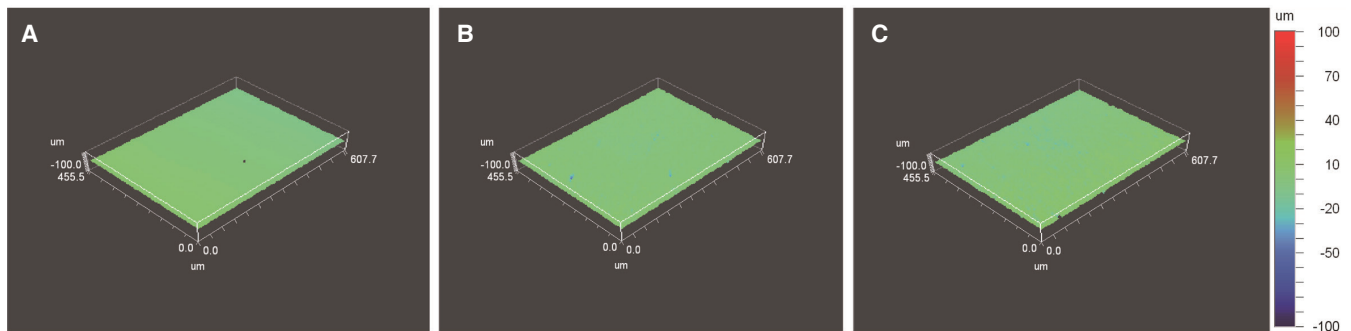
	Pristine		Scaling		Surface polishing	
	Average (SD)	<i>P</i> value	Average (SD)	<i>P</i> value	Average (SD)	<i>P</i> value
Metal alloy	3.02 (± 0.34)		2.44 (± 0.72)		3.49 (± 0.72)	
Lithium disilicate	2.35 (± 1.05)	.56	28.54 (± 9.64)	.002*	56.66 (± 9.12)	.002*
Zirconia	1.65 (± 0.42)		101.37 (± 18.75)		29.57 (± 18.86)	

The asterisk (\*) indicates that there is statistically significant difference. *P* < .05.

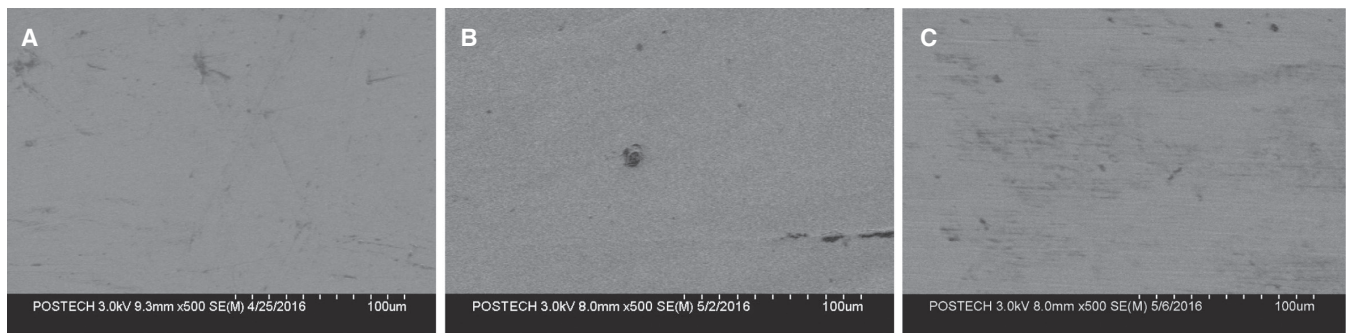
Before the ultrasonic scaling (pristine step), there was no significant difference in the surface roughness values among three different restorative materials ( $P = .56$ , Table 3). After repeated scaling, however, the zirconia discs showed the highest mean roughness value, while the metal alloy discs exhibited the lowest ( $P < .05$ ). After surface polishing with intraoral kits, the mean surface roughness was the highest in the lithium disilicate group, followed in the order of the zirconia and nickel-chromium alloy group ( $P < .05$ ). In addition, the zirconia group showed the largest changes in surface roughness values among the tested materials.

Microscopic observation showed that the surface of metal alloy disc was not greatly affected by the ultrasonic scaling

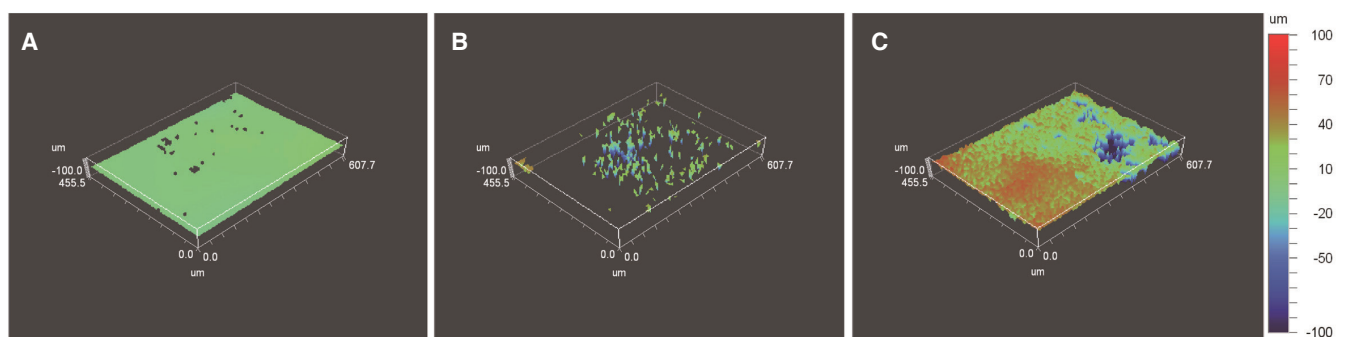
or surface polishing (Fig. 1 and Fig. 2). For the lithium disilicate glass ceramic, the pristine glazed surface was shown to be relatively uniform, whereas the severely scratched patterns were observed after repeated scaling (Fig. 3 and Fig. 4). The roughened surface of lithium disilicate was not sufficiently changed into original smooth condition even after multi-step polishing (Fig. 3 and Fig. 4). For the zirconia group, the pristine surface after glazing showed low surface roughness (Fig. 5 and Fig. 6). The highly damaged surface of the test zirconia specimen after repeated scaling was significantly altered after multi-step polishing with intraoral kit, resulting in a mostly smooth surface (Fig. 5 and Fig. 6).



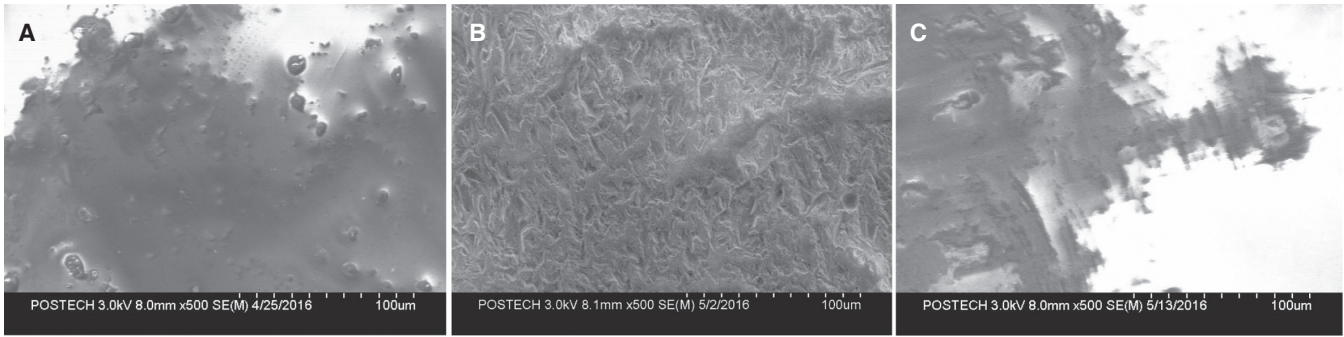
**Fig. 1.** A representative 3D plot image of metal (nickel-chromium) alloy; (A) pristine, (B) after repeated scaling for 20 seconds, (C) after surface polishing with an intraoral polishing kit.



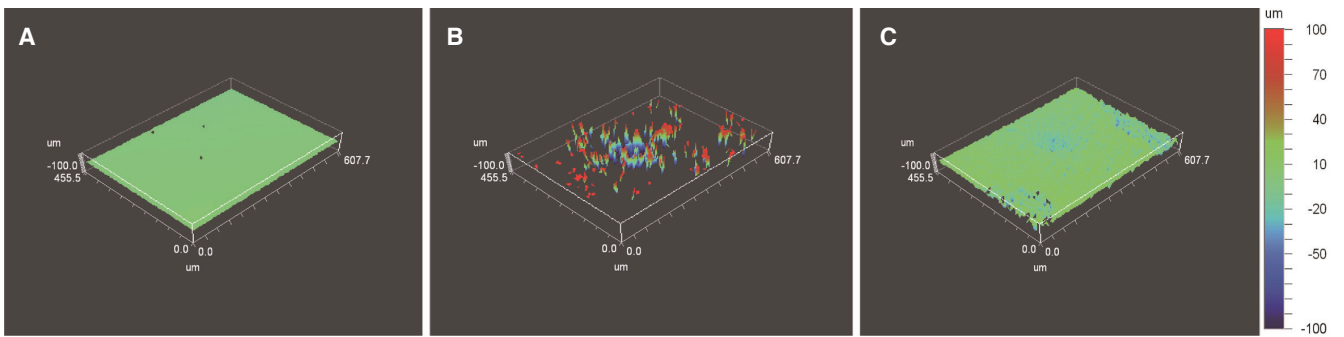
**Fig. 2.** A representative SEM image of metal (nickel-chromium) alloy ( $\times 500$  magnification); (A) pristine, (B) after repeated scaling, (C) after surface polishing with an intraoral polishing kit.



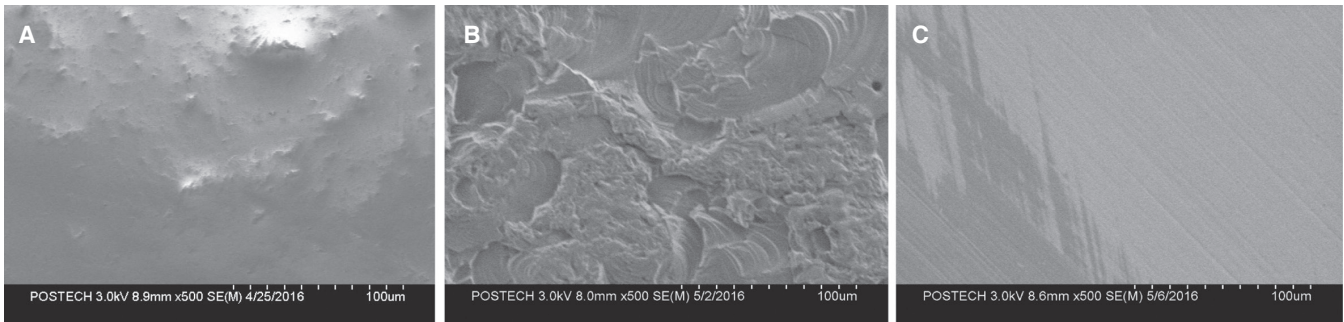
**Fig. 3.** A representative 3D plot image of lithium disilicate; (A) pristine (glazed), (B) after repeated scaling for 20 seconds, (C) after multi-step polishing with an intraoral polishing kit.



**Fig. 4.** A representative SEM image of lithium disilicate ( $\times 500$  magnification); (A) pristine (glazed), (B) after repeated scaling, (C) after multi-step polishing with an intraoral polishing kit.



**Fig. 5.** A representative 3D plot image of zirconia; (A) pristine (glazed), (B) after repeated scaling for 20 seconds, (C) after multi-step polishing with an intraoral polishing kit.



**Fig. 6.** A representative SEM image of zirconia ( $\times 500$  magnification); (A) pristine (glazed), (B) after repeated scaling, (C) after multi-step polishing with an intraoral polishing kit.

## DISCUSSION

This study examined the *in-vitro* effect of the repeated use of an ultrasonic scaler equipped with a stainless steel tip and subsequent surface treatment using an intraoral polishing kit on the surface roughness values of three different restorative materials: metal alloy, lithium disilicate, and zirconia. Based on the results of this study, the null hypothesis was rejected. It is important to establish surface conditions favorable to oral hygiene maintenance considering the characteristics of restorative materials. According to a previous study about repeated scaling on restorative materials, the surfaces were increasingly roughened as the time of instrumentation

increased.<sup>26</sup> In this study, the effect of repeated scaling and subsequent surface polishing was different depending on the type of materials used. The surface roughness change of metal alloy was almost none for each treatment steps, considering the error range of the 3D profiler measurements. Similar mechanical properties of both nickel-chromium alloy disc and stainless steel ultrasonic scaler tip may have affected the results of this study.<sup>29</sup> However, the surfaces of the lithium disilicate and zirconia discs were significantly roughened after repeated scaling. A previous study revealed that the use of a titanium-based or stainless steel periodontal curette increased the surface roughness of lithium disilicate and zirconia.<sup>27</sup> The result was in consistent with the

findings of the current study, showing that the ultrasonic scaling has a negative effect on the surface morphology of ceramic material.

The probabilities for periodontal inflammation and plaque accumulation increase when the surface roughness of the restorative material is more than that of the occlusal contact area of natural teeth.<sup>32</sup> Thus, it is important to smoothen the rough surfaces of restorative materials from ultrasonic scaling by using an intraoral polishing system. In fact, intraoral polishing of ceramic restorative material is reported to be difficult due to its high hardness.<sup>33</sup> In this study, the surface roughness of the lithium disilicate group significantly increased after multi-step polishing. A previous study reported that the glaze finishing, rather than surface polishing with carborundum or silicon points, improved the surface integrity of the lithium disilicate.<sup>34</sup> Based on the manufacturer's information, the glass ceramic discs tested in this study (IPS. E.max Press) consisted of 70 vol% needle-like crystals of lithium disilicate, which were crystallized in and firmly bonded to a glassy matrix. High crystal content of lithium disilicate ceramic and glazing porcelain may have caused an uneven surface even after polishing.<sup>35</sup> In case of grinding with diamond burs, the polishing could wear away the irregularities of the roughened surface of lithium disilicate even after the removal of glazed layer.<sup>31,36</sup> However, roughening with an ultrasonic scaler may be different with the grinding with a fine diamond bur. It can be speculated that the repeated ultrasonic scaling could damage the surfaces of underlying lithium disilicate structure as well as overlying glazed feldspathic porcelain layer. Therefore, the polishing with intraoral kits may not be sufficient to restore the original surface roughness, or even worsen the surface integrity due to cracked residual feldspathic porcelain particles or partially dislodged lithium disilicate crystals. Further studies are required to clarify the effectiveness of intraoral surface polishing for the lithium disilicate. On the other hand, the zirconia (3Y-TZP) showed marked reduction of surface roughness and smoothened surface after polishing with an intraoral kit, although its surface was layered with glazing feldspathic porcelain. This finding was in accordance with the previous study.<sup>36</sup> Even though ultrasonic scaling may be different with the grinding in relation to the aspect of roughening procedure, one may speculate that the negative effect of repeated scaling on the surface roughness of zirconia may be recovered after meticulous surface polishing due to the homogeneous and fine microstructure of the zirconia. The removal of glazed layer from the ceramic surface leads to significant changes in wear characteristics, abrasion resistance, and mechanical strength.<sup>31</sup> The intraoral polishing may affect the longevity and biocompatibility of the ceramics.<sup>31</sup> For the zirconia ceramic, multi-step surface polishing with intraoral kits after repeated ultrasonic scaling was effective, and therefore can be recommended.

In this study, reciprocal (forward and reverse) movement was used for the 'repeated scaling' treatment on the surface of the test materials, while the polishing was conducted in one direction to implement a standardized technique. This

may have caused the effect of surface polishing less significantly than expected. Researchers of recent studies on the intraoral polishing of ceramics performed the polishing in the identical direction of the instrumentation (grinding with diamond burs) used to roughen the material surfaces.<sup>31,37</sup> The differences in the surface roughness values between this study and the others may have originated from the differences in the roughening method (grinding or scaling), polishing method, and surface finishing (glazed or as-milled, polished).<sup>31,35,37</sup>

The limitations of this *in-vitro* pilot study is that only three restorative materials with small sample sizes were evaluated for ultrasonic scaling and surface polishing, which necessitates an additional experiment for a wide variety of restorative materials including dental polymers. In addition, the surface roughness was only evaluated using the 2D roughness profile (Ra value) instead of the 3D roughness profile (Sa value). Considering the clinical situations, the effects of scaling on the surface roughness of restorative materials with the forms of crowns and bridges should be evaluated in the following *in-vitro* studies. Moreover, clinically controlled studies with various intraoral restorations using ultrasonic scalers and intraoral polishing kits should also be required in the future.

## CONCLUSION

Within the limitations of this study, the following conclusions can be drawn:

1. The nickel-chromium alloy showed similar surface roughness (Ra) values before scaling (pristine), after repeated scaling, and after surface polishing.
2. The mean Ra value for lithium disilicate group significantly increased after repeated scaling, and even after surface polishing.
3. The mean Ra value for zirconia group significantly increased after repeated scaling and decreased after multi-step polishing.
4. The mean Ra values of the metal alloy and high-strength ceramics measured at two different treatment steps, scaling and surface polishing, were significantly different.

## ORCID

Hyung-In Yoon <https://orcid.org/0000-0002-9597-6342>

Eun-Jin Park <https://orcid.org/0000-0001-6383-449X>

## REFERENCES

1. Axelsson P, Nyström B, Lindhe J. The long-term effect of a plaque control program on tooth mortality, caries and periodontal disease in adults. Results after 30 years of maintenance. *J Clin Periodontol* 2004;31:749-57.
2. Axelsson P, Lindhe J. Effect of controlled oral hygiene procedures on caries and periodontal disease in adults. Results after 6 years. *J Clin Periodontol* 1981;8:239-48.
3. Axelsson P, Lindhe J. The significance of maintenance care in

- the treatment of periodontal disease. *J Clin Periodontol* 1981; 8:281-94.
4. Pameijer CH, Stallard RE, Hiep N. Surface characteristics of teeth following periodontal instrumentation: a scanning electron microscope study. *J Periodontol* 1972;43:628-33.
  5. Breininger DR, O'Leary TJ, Blumenshine RV. Comparative effectiveness of ultrasonic and hand scaling for the removal of subgingival plaque and calculus. *J Periodontol* 1987;58:9-18.
  6. Sherman PR, Hutchens LH Jr, Jewson LG, Moriarty JM, Greco GW, McFall WT Jr. The effectiveness of subgingival scaling and root planning. I. Clinical detection of residual calculus. *J Periodontol* 1990;61:3-8.
  7. Drisko CH. Root instrumentation. Power-driven versus manual scalers, which one? *Dent Clin North Am* 1998;42:229-44.
  8. Kerry GJ. Roughness of root surfaces after use of ultrasonic instruments and hand curettes. *J Periodontol* 1967;38:340-6.
  9. Busslinger A, Lampe K, Beuchat M, Lehmann B. A comparative in vitro study of a magnetostrictive and a piezoelectric ultrasonic scaling instrument. *J Clin Periodontol* 2001;28:642-9.
  10. Oliveira G, Macedo PD, Tsurumaki JN, Sampaio JE, Marcantonio R. The effect of the angle of instrumentation of the Piezoelectric Ultrasonic Scaler on root surfaces. *Int J Dent Hyg* 2016;14:184-90.
  11. Wilkinson RF, Maybury JE. Scanning electron microscopy of the root surface following instrumentation. *J Periodontol* 1973;44:559-63.
  12. Kawai K, Urano M. Adherence of plaque components to different restorative materials. *Oper Dent* 2001;26:396-400.
  13. Quirynen M, Bollen CM. The influence of surface roughness and surface-free energy on supra- and subgingival plaque formation in man. A review of the literature. *J Clin Periodontol* 1995;22:1-14.
  14. Yilmaz C, Korkmaz T, Demirköprülü H, Ergün G, Ozkan Y. Color stability of glazed and polished dental porcelains. *J Prosthodont* 2008;17:20-4.
  15. Aykent F, Yondem I, Ozyesil AG, Gunal SK, Avunduk MC, Ozkan S. Effect of different finishing techniques for restorative materials on surface roughness and bacterial adhesion. *J Prosthet Dent* 2010;103:221-7.
  16. Weaks LM, Lescher NB, Barnes CM, Holroyd SV. Clinical evaluation of the Prophy-Jet as an instrument for routine removal of tooth stain and plaque. *J Periodontol* 1984;55:486-8.
  17. Lee SG, Lim SB, Chung CH, Kwon SH. Analysis of surface form change after performing prophylaxis procedure on implant surface using various oral hygiene instruments. *J Korean Acad Periodontol* 2004;34:1-17.
  18. Lee AR, Chung CH, Jung GU, Pang EK. The effect of copper alloy scaler tip on the surface roughness of dental implant and restorative materials. *J Korean Acad Prosthodont* 2014; 52:177-185.
  19. Brecker SC. Porcelain baked to gold-A new medium in prosthodontics. *J Prosthet Dent* 1956;6:801-10.
  20. Della Bona A, Mecholsky JJ, Barrett AA, Griggs JA. Characterization of glass-infiltrated alumina-based ceramics. *Dent Mater* 2008;24:1568-74.
  21. Kang JI, Heo YR, Lee MS, Son MK. Understanding and trends of esthetic treatment in prosthodontics: IPS e.max. *J Korean Soc Dent Hyg* 2014;14:447-52.
  22. Raigrodski AJ. Clinical and laboratory considerations for the use of CAD/CAM Y-TZP-based restorations. *Pract Proced Aesthet Dent* 2003;15:469-76.
  23. Conrad HJ, Seong WJ, Pesun IJ. Current ceramic materials and systems with clinical recommendations: a systematic review. *J Prosthet Dent* 2007;98:389-404.
  24. Kang JI, Heo YR, Lee MS, Son MK. Understanding and trends of esthetic treatment in prosthodontics: part 2. Zirconia. *J Korean Soc Dent Hyg* 2014;14:617-22.
  25. Volpato CAM, Fredel MC, Philippi AG, Petter CO. Ceramic materials and color in dentistry. INTECH Open Access Publisher; 2010.
  26. Lee SC, Chung CH, Yim SB. The stereomicroscope and SPM study on the marginal change of porcelain crown in various repeated instrumentations for periodontal therapy. *J Korean Acad Periodontol* 2000;30:455-70.
  27. Vigolo P, Buzzo O, Buzzo M, Mutinelli S. An in vitro evaluation of alumina, zirconia, and lithium disilicate surface roughness caused by two scaling instruments. *J Prosthodont* 2015 Dec 18.
  28. Patterson CJ, McLundie AC, Stirrups DR, Taylor WG. Efficacy of a porcelain refinishing system in restoring surface finish after grinding with fine and extra-fine diamond burs. *J Prosthet Dent* 1992;68:402-6.
  29. Ward MT, Tate WH, Powers JM. Surface roughness of opalescent porcelains after polishing. *Oper Dent* 1995;20:106-10.
  30. Chu FC, Frankel N, Smales RJ. Surface roughness and flexural strength of self-glazed, polished, and reglazed In-Ceram/Vitadur Alpha porcelain laminates. *Int J Prosthodont* 2000; 13:66-71.
  31. Vrochari AD, Petropoulou A, Chronopoulos V, Polydorou O, Massey W, Hellwig E. Evaluation of surface roughness of ceramic and resin composite material used for conservative indirect restorations, after repolishing by intraoral means. *J Prosthodont* 2015 Oct 21.
  32. Willems G, Lambrechts P, Braem M, Vuylsteke-Wauters M, Vanherle G. The surface roughness of enamel-to-enamel contact areas compared with the intrinsic roughness of dental resin composites. *J Dent Res* 1991;70:1299-305.
  33. Haywood VB, Heymann HO, Scurria MS. Effects of water, speed, and experimental instrumentation on finishing and polishing porcelain intra-orally. *Dent Mater* 1989;5:185-8.
  34. Odatsu T, Jimbo R, Wennerberg A, Watanabe I, Sawase T. Effect of polishing and finishing procedures on the surface integrity of restorative ceramics. *Am J Dent* 2013;26:51-5.
  35. Sasahara RM, Ribeiro Fda C, Cesar PF, Yoshimura HN. Influence of the finishing technique on surface roughness of dental porcelains with different microstructures. *Oper Dent* 2006;31:577-83.
  36. Amaya-Pajares SP, Ritter AV, Vera Resendiz C, Henson BR, Culp L, Donovan TE. Effect of Finishing and Polishing on the Surface Roughness of Four Ceramic Materials after Occlusal Adjustment. *J Esthet Restor Dent* 2016;28:382-96.
  37. Preis V, Grumser K, Schneider-Feyrer S, Behr M, Rosentritt M. The effectiveness of polishing kits: influence on surface roughness of zirconia. *Int J Prosthodont* 2015;28:149-51.