THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Caries management by risk assessment (CAMBRA) and its effect on the surface roughness of various restorative materials

Lauren M. Bolding, DDS, MS,[a] Radi Masri, BDS, MS, PhD,[b] Dwayne Arola, PhD,[c] Carl F. Driscoll, DMD,[d] and Elaine Romberg, PhD[e]

ABSTRACT

Statement of problem. Whether topical anticaries medicaments used in the oral environment will affect the surface integrity of restorative materials is uncertain.

Purpose. The purpose of this in vitro study was to investigate the effect of various anticaries agents on the surface roughness of 3 different restorative materials.

Material and methods. Sixty-four specimens of each restorative material (feldspathic porcelain, Ni-Cr metal ceramic alloy, and Ti-6Al-4V titanium alloy) were prepared and separated into 4 equal groups for soaking in anticaries agents (Prevident Dental Rinse, ACT mouth wash, chlorhexidine gluconate, and water). A profilometer was used to measure surface roughness before and after soaking the materials for 2 years of simulated usage. The mean change in surface roughness for each specimen was calculated. Statistical analysis was performed with a 2-way ANOVA, followed by the Tukey HSD test (α=.05).

Results. A significant interaction was found between the materials and anticaries agents (F=2.64, *P*=.02). The significant interaction was between Prevident and chlorhexidine gluconate. Porcelain specimens soaked in Prevident produced a negative change (−0.072 ±0.35 μm) in surface roughness (smoother surface), while chlorhexidine gluconate produced a positive change (0.094 ±0.42 μm) in surface roughness (rougher surface).

Conclusion. Within the limitations of this in vitro study, it can be concluded that Prevident Dental Rinse and chlorhexidine gluconate may cause a change in the surface roughness of feldspathic porcelain. (J Prosthet Dent 2015;114:543-548)

In April 2002, a consensus conference of the California Dental Association regarding caries management, prevention, and risk assessment provided mechanisms and guidelines for caries management by risk assessment (CAMBRA).[1] Featherstone et al[1] believed that by classifying a patient into a caries risk group and following the CAMBRA guidelines, there would be a shift to treating the bacteria involved in the development of dental caries rather than just excavating caries and restoring cavities. Individuals at high risk for caries were advised to receive testing for bacterial levels, fluoride therapy at a dental office and at home, 0.12% chlorhexidine therapy for 2 weeks daily every 3 months, and regular recall at 3-month intervals to monitor caries progression or arrestment and success of antibacterial therapy.[2]

Fluoride is recommended because it can inhibit demineralization, enhance remineralization, and inhibit bacterial activity. The methods of topical fluoride delivery include dentifrices and mouth rinses, both of which are available in over-the-counter strength and prescription strength and as professionally applied varnishes, foams, and gels.[1] Several studies have shown that fluoride has detrimental effects on restorative materials, including metal alloys[3] and porcelain.[4-6]

In 2004, Butler et al[7] demonstrated that feldspathic porcelain and aluminous porcelain showed a significant increase in surface roughness when subjected to 1.23%

[a]Former Resident, Postgraduate Prosthodontics, Department of Endodontics, Prosthodontics and Operative Dentistry, School of Dentistry, University of Maryland, Baltimore, Md.
[b]Associate Professor, Department of Endodontics, Prosthodontics and Operative Dentistry, School of Dentistry, University of Maryland, Baltimore, Md.
[c]Professor, Department of Mechanical Engineering, University of Maryland, Baltimore, Md.
[d]Program Director and Professor, Postgraduate Prosthodontics, Department of Endodontics, Prosthodontics and Operative Dentistry, University of Maryland, Baltimore, Md.
[e]Professor Emerita, Department of Orthodontics and Pediatric Dentistry, University of Maryland, Baltimore, Md.

Clinical Implications

Clincians should exercise caution when prescribing mouth rinses and topical medicaments because they can affect a porcelain surface.

acidulated phosphate fluoride (APF) and stannous fluoride, while ultralow-fusing porcelain showed a significant increase in surface roughness only after being subjected to 1.23% APF. In addition, 1500 ppm sodium fluoride (NaF) solution can affect commercially pure titanium and increase levels of bacterial adherence.[8,9]

Chlorhexidine gluconate, a broad spectrum antiseptic, has been found to be effective in reducing the microbial challenge associated with dental caries.[10] Some authors[11,12] reported that chlorhexidine was moderately effective in preventing caries, while others found the strength of the evidence insufficient for all anticaries solutions other than fluoride.[13] Chlorhexidine has been shown to cause extrinsic discoloration of teeth and porcelain. The etiology of this action is not fully understood.[14,15]

Several studies have demonstrated a positive correlation between surface roughness and bacterial adhesion on restorative materials.[16-18] Multiple authors have suggested a threshold surface roughness for prosthetic materials below which there is no change in bacterial plaque retention. This threshold value is reported as 0.2 μm by some authors and 0.4 μm by others.[19,20]

With the development of CAMBRA guidelines has come the application of many more anticaries regimens by dentists and their patients, for example, fluoride in the form of gels, pastes, and rinses; xylitol in the form of rinses, lozenges, and gum; chlorhexidine rinses; and sodium bicarbonate pastes and rinses.[22] With these topical products being increasingly used by patients to prevent caries, how they will affect the restorations existing in the mouth is important.

The purpose of this study was to investigate the effect of various anticaries agents on the surface roughness of 3 different restorative materials. The null hypothesis was that no difference would be found in the change in surface roughness between restorative materials, anticaries agents, or the interaction between them.

MATERIAL AND METHODS

The effect of various anticaries agents on the surface roughness of porcelain, titanium, and base metal was examined. Soaking of the various materials in each solution was carried out to simulate 2 years of usage. The total number of specimens in each restorative material group was 64, and the total number of specimens in each anticaries agent group was 48. Measurements were made in 2 directions for each specimen, and both values were included in the statistical analysis, doubling the number of readings for each group. These measurements were considered statistically independent in that different areas and directions were measured on the specimen.

Three different anticaries agents recommended in the CAMBRA guidelines were used in this study. Prevident Dental Rinse (Colgate Oral Pharmaceuticals) was used as the prescription-strength fluoride mouthwash. ACT mouthwash (Chattem Inc) was used as the over-the-counter fluoride mouthwash. A solution of 0.12% chlorhexidine gluconate (Sunstar Americas Inc) was also used. Distilled water served as the control.

Three different materials were used to fabricate the test disks. To fabricate the disks, porcelain powder (Ceramco 3; Dentsply Intl) was mixed with sculpting liquid (Ceramco 3; Dentsply Intl) and stacked onto a glass slab (Henry Schein Inc) to form a wide area of porcelain with approximately 3-mm thickness, measured with a periodontal probe (Henry Schein Inc). A 12-mm diameter copper band (Henry Schein Inc) was used to cut the porcelain into disks. The disks were then sintered according to the manufacturer's recommendation (940°C) and autoglazed in a porcelain oven (Jelfire VPF; Jelenko). Any porosities on the surface of the disks were filled with porcelain, and the disks were sintered for a second bake (934°C). The disks were then hand polished with rubber polishing wheels (DiaLite; Brasseler USA Inc), with the sequence of bulk reduction, prepolish, and high-shine, allowing 20 seconds of polishing time with each wheel as described in previous studies.[7] After hand-polishing, the disks were replaced onto the porcelain oven for an autoglaze cycle (921°C).

To fabricate the base metal alloy disks, a mold (10 mm in diameter and 2 mm in thickness) was made from polyvinyl siloxane putty (Coltène Lab-Putty; Coltène/Whaledent Inc). Casting wax (Pro-Art Wax; Ivoclar Vivadent AG) was melted into the mold to form disks. Once the wax hardened, it was removed from the mold, sprued at a 45-degree angle from the edge of the disk, and positioned in a casting ring (Whip Mix Corp). Phosphate-bonded investment (Ceramigold; Whip Mix Corp) was mixed according to the manufacturer's instructions and used to invest the wax disks. The investment was allowed to bench set for 90 minutes and then was placed in a wax elimination oven (Infinity L30, Jelrus; Whip Mix Corp) in accordance with the manufacturer's recommended time and temperature. Once wax elimination was complete, the disks were cast from a base metal alloy (Rexillium III; Core Dental Labs). Once cooled, the investment was broken away from the metal disks and the remaining investment was airborne-particle abraded (Basic Master; Renfert USA) until the disks were free of investment. The disks were separated from the sprue, and the area of the sprue attachment was contoured to match the contour of the disk.

Table 1. Immersion time of specimens in anticaries agents

Anticaries Agent	Immersion Time (2 years equivalent), h
Prevident Dental Rinse	12
ACT mouthwash	12
Chlorhexidine gluconate	3
Distilled water	12

Table 2. Initial surface roughness values

Material and Anticaries Agent	Initial Ra, μm (Mean ±SD)
Porcelain	
Prevident	0.75 ±0.60
ACT	0.62 ±0.28
Chlorhexidine	0.66 ±0.44
Water	0.84 ±0.62
Base metal	
Prevident	0.26 ±0.09
ACT	0.28 ±0.14
Chlorhexidine	0.22 ±0.08
Water	0.34 ±0.09
Titanium	
Prevident	0.35 ±0.11
ACT	0.31 ±0.08
Chlorhexidine	0.39 ±0.14
Water	0.39 ±0.11

The disks were then mounted in a mound of plaster (Modern Materials; Heraeus Kulzer), and the block of disks were polished on a diamond model trimmer (Whip Mix Corp). The disks were then hand polished by using the following sequence: heatless stone (Mizzy Inc), coarse pink stone, medium pink stone, fine white stone (Axis Dental Corp), brownie wheel, greenie wheel (Shofu Dental Corp), and polishing compound (Renfert USA). Each step was performed for 20 seconds for each disk.

Prefabricated titanium alloy (Ti6Al4V) bars (100×10×10 mm) were obtained from the Biomet 3i implant company. Ten-millimeter segments were marked on each bar, and the bars were sectioned with a carbide rotary cutting instrument (Great White; SS White)[21] in an electric handpiece (Bien Air Surgery) at 40 rpm under copious water irrigation. No surface preparation was performed on the titanium alloy specimens.

The initial surface roughness (Ra_i) was measured for each disk with a profilometer (Hommel-Etamic T8000 RC; Jenoptic). The profilometer was calibrated with a standard reference specimen and set to travel at 0.1 mm/s with a range of 600 μm during testing and an amplitude transmittance set at 50%. A mark was drawn perpendicular to the specimen surface on the side of each disk with a permanent marker (Sharpie; Sanford LP).

Each disk was placed on the profilometer table with the mark at a right angle to the line drawn by the profilometer tip during the testing. The starting point for each reading was approximately 2 mm from the edge of the testing surface, and the line traced by the profilometer tip went through the middle of the disk surface. The disks were subjected to a 5-μm tip radius diamond stylus under a constant measuring force of 3.9 mN. Each disk was analyzed by 2 passes of the profilometer, with the second pass perpendicular to the first. Each individual value for Ra was used for statistical analysis because these values were considered statistically independent.

Before the disks were subjected to soaking, a diamond rotary cutting instrument (Brasseler USA Inc) was used to trace the original mark on each specimen. One disk of each restorative material was placed in each of the testing solutions in a closed plastic container and allowed to soak for a simulated 2-year period. This was according to the recommended pattern of usage dictated by CAMBRA guidelines, which is 30 seconds, twice daily for both Prevident Dental Rinse and ACT mouth rinse and 30 seconds, twice daily for 2 weeks each month). The soaking time for each solution is listed in Table 1. Each solution, except for the distilled water, was changed every 30 minutes.

After each disk was immersed in its solution for the designated amount of time, it was rinsed with distilled water and air-dried. Each disk was placed into an individual container marked to identify the solution in which it was immersed and its initial Ra value.

Each specimen was placed on the table of the profilometer with the mark in the same direction as it had been for the initial reading. The final surface roughness value (Ra_f) for the surface roughness of each material was obtained with a profilometer, in the same manner as the initial readings and recorded.

Before specimen fabrication, a power analysis was completed to determine sample size. With an n=16, an α level of .05, an effect size of 0.25, and 3 different anticaries agents plus water as a control, the power was 0.81. For comparison of the surface roughness of the 3 restorative materials, with n=16, an α level of .05, and an effect size of 0.25, the power was 0.89.

The difference between the initial and final values of surface roughness was analyzed with 2-way ANOVA. The equation used for change in surface roughness was

$$Ra_{change}=Ra_f-Ra_i.$$

Significant differences between the anticaries agents and between the restorative materials were further analyzed by Tukey test (α=.05).

RESULTS

The initial values for the surface roughness of each group of specimens are listed in Table 2. This demonstrates that the porcelain specimens in all groups were rougher than both the base metal and titanium alloy specimens.

Table 3. Final surface roughness values

Material and Anticaries Agent	Final Ra, μm (Mean ±SD)
Porcelain	
Prevident	0.56 ±0.20
ACT	0.69 ±0.45
Chlorhexidine	0.93 ±0.83
Water	0.84 ±0.44
Base metal	
Prevident	0.24 ±0.06
ACT	0.27 ±0.10
Chlorhexidine	0.23 ±0.08
Water	0.35 ±0.09
Titanium	
Prevident	0.34 ±0.13
ACT	0.33 ±0.07
Chlorhexidine	0.38 ±0.15
Water	0.38 ±0.10

Table 4. Change in surface roughness values

Material	Change in Ra, μm (Mean ±SD)
Porcelain	
Prevident	-0.19 ±0.58
ACT	0.07 ±0.47
Chlorhexidine	0.27 ±0.69
Water	0 ±0.74
Base metal	
Prevident	-0.01 ±0.09
ACT	0.02 ±0.08
Chlorhexidine	-0.01 ±0.04
Water	-0.01 ±0.06
Titanium	
Prevident	-0.02 ±0.07
ACT	-0.01 ±0.04
Chlorhexidine	0.02 ±0.04
Water	0.01 ±0.07

Table 3 lists the final values for surface roughness for each group of specimens, and Table 4 lists the change in surface roughness for each group of specimens, again showing greater values in the porcelain group.

Statistical analysis with factorial ANOVA (Table 5) revealed no significant difference in mean change in surface roughness among the 3 materials (F=.474, *P*=.62): porcelain (0.038 ±64 μm), base metal (0.001 ±0.07 μm), and titanium alloy (−0.003 ±0.06 μm). Statistically significant differences were found within the anticaries agents group (F=3.318, *P*=.02) and also in the interaction between the materials and anticaries agents (F=2.64, *P*=.02).

Post hoc analysis (Table 5) revealed that the significant difference in mean change in surface roughness was between Prevident Dental Rinse (−0.072 ±0.35 μm) and chlorhexidine gluconate (0.094 ±0.42 μm). Prevident Dental Rinse produced a negative change in surface roughness, or a smoother surface, compared with chlorhexidine gluconate, which produced a positive change in surface roughness, or a rougher surface. No significant difference was found between the Prevident Dental Rinse, distilled water (0.001 ±0.43) μm, and ACT (0.026 ±0.28 μm). No significant difference was found between water, ACT, and chlorhexidine gluconate.

Figure 1 illustrates the significant interaction between the anticaries agents and the restorative materials (F=2.64, *P*=.02). The interaction between the 4 anticaries agents and titanium alloy and base metal were clinically unimportant. However, the interaction between 2 of the 4 anticaries agents and porcelain was large and clinically meaningful.

DISCUSSION

The present study evaluated the effects of 3 CAMBRA-recommended anticaries agents on 3 commonly used

Table 5. Results of factorial ANOVA examining anticaries agents and restorative materials

Source	*df*	Mean Square	F	*P*
Material	2	0.06	0.474	.62
Agent	3	0.45	3.313	.02
Material×agent	6	0.36	2.640	.02
Error	372	0.14		
Total	383			

dental materials. No significant difference was found in the surface roughness of the 3 restorative materials, supporting the null hypothesis. Although a significant difference was found in the anticaries agents, this difference occurred because of the significant interaction between the anticaries agents and restorative materials (Fig. 1). Significant difference between Prevident and chlorhexidine only occurred with the porcelain specimens. It did not occur for titanium alloy or base metal (Fig. 1).

Prevident Dental Rinse produced no significant changes when used with base metal or titanium, but produced a negative change in surface roughness when used with porcelain. This suggests that the porcelain surface became significantly smoother overall when soaked in the Prevident Dental Rinse. Prevident Dental Rinse contains 0.2% neutral sodium fluoride. This finding is not consistent with previous studies using the same type of porcelain as the present study. Acidulated phosphate fluoride has been shown to have a greater ability to increase the surface roughness of porcelain than neutral sodium fluoride, which produces no significant change in the surface roughness of porcelain surfaces when compared with controls.[4-6]

Another component of Prevident Dental Rinse is benzoic acid, which also serves as a preservative in many foods. Literature that supports a direct association between a change in surface roughness of dental

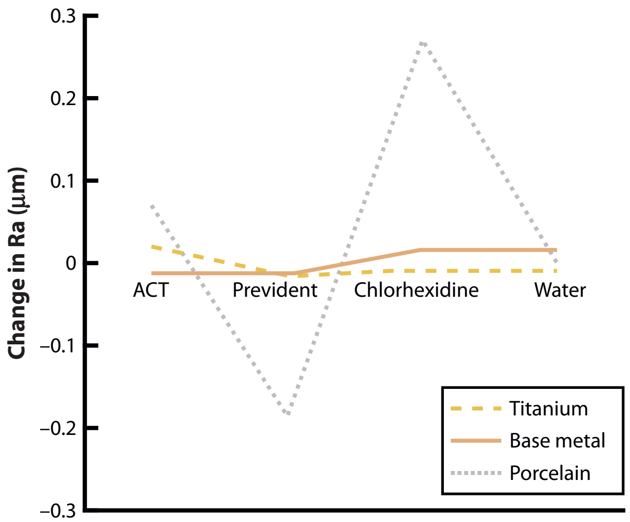

Figure 1. Interaction between restorative materials and anticaries agents and their effect on surface roughness.

restorative materials and benzoic acid is scarce; however, studies are available that demonstrate potentially deleterious effects of acidic mouthwashes, organic acids, and acidic food and drinks on natural teeth by removing all or part of the dentin smear layer, thus leading to dentin hypersensitivity.[22,23] One study evaluated the permeability of dentin after a single exposure to acidic soft drinks with different acid compositions, one of which contained benzoic acid. All the drinks tested increased dentin permeability by removing the smear layer.[24] Aside from these studies, which were performed on dentin and not porcelain, the effect demonstrated is one that would be expected to increase surface roughness if the initial surface was very smooth. However, if the initial surface of a material was rough and a solution had an etching effect on it, this may actually produce a smoother surface, which could account for the results of the current study.

Prevident Dental Rinse produced no significant changes in the surface roughness of base metal or titanium alloy. These results support previous literature, which showed no effect of neutral sodium fluoride on the surface roughness of dental metal restorations.[8]

ACT mouth rinse produced no significant changes in surface roughness on any of the 3 restorative materials. ACT mouth rinse contains 0.05% neutral sodium fluoride and is alcohol-free. Based on the results of previous studies, the difference in effect between ACT mouth rinse and Prevident Dental Rinse on porcelain cannot be explained by the different concentrations of fluoride in the solution, the pH of the solution, or the alcohol content of the solution.[4,25] Other studies have shown that acidulated phosphate fluoride is associated with an increase in the surface roughness of feldspathic porcelain because of its lower pH and increased etching potential.[7,26]

Chlorhexidine gluconate mouth rinse produced no significant changes in surface roughness on base metal or titanium, but did produce a significant positive, and clinically important, change in the surface roughness of porcelain. One explanation for the rougher surface could be the well-known staining of porcelain that chlorhexidine gluconate produces. Few studies have evaluated chlorhexidine staining of porcelain or metals; however, since the nature of this staining is proposed to be extrinsic, similar results would probably be seen. If the increase in the surface roughness of porcelain produced by chlorhexidine gluconate is not due to staining and is not reversible, this could have clinical relevance if the resultant surface roughness is brought above the threshold value for increased bacterial accumulation, which varies in the literature from 0.2 to 0.4 µm.[19,20]

The difference in effect on the surface roughness of the various materials can best be explained by specimen preparation and the nature of the material. The titanium alloy bars were obtained polished from the manufacturer. The base metal disks were embedded in groups into a plaster mound and polished first on a diamond wheel trimmer, followed by the remaining rubber polishers and polishing compound. These methods allowed for consistency in the initial surface roughness among specimens.

The porcelain polishing had to be done completely by hand with rubber disks because a diamond wheel trimmer might have fractured the porcelain specimens. The standard deviations in surface roughness of the porcelain specimens were greater than those of the titanium alloy and base metal specimens.

Although each specimen was marked to maintain the same positioning on the profilometer for initial and final readings, it was not guaranteed that the exact same line would be traced in its entirety by the tip. The standard deviations for each material are listed in Table 5. The standard deviation for porcelain for all anticaries agents (0.64) was 9 times larger than that for base metal and more than 10 times larger than that for titanium. This appears to reflect the lack of uniformity in the polishing process of the porcelain specimens.

Other limitations to this study include the sole use of the profilometer to evaluate the surface roughness of the materials. Using a scanning electron microscope before and after soaking in the solutions might have given more information regarding the nature of the surface change in the specimens. Also, the specimens were only soaked in the mouth rinses without the application of mechanical stimulation, which could have affected the surface roughness of a restorative material, depending on the components of the toothpaste, hardness of the bristles, and/or the brushing technique. The changes in surface roughness found in this study might have been larger if the mouth rinses had been used in combination with tooth brushing.

CONCLUSION

This study evaluated the effect of 3 anticaries mouth rinses on the change in the surface roughness of 3 commonly used restorative dental materials. Significant differences were found for the porcelain group when subjected to Prevident Dental Rinse and chlorhexidine gluconate. Within the limitations of this study, it can be concluded that Prevident Dental Rinse and chlorhexidine gluconate may cause a change in the surface roughness of porcelain when used for a period of 2 years.

Prevident Dental Rinse may increase the surface roughness of porcelain, while chlorhexidine gluconate may decrease the surface roughness of porcelain. Further studies with more controlled polishing and other methods of surface evaluation are recommended to investigate the effect of Prevident Dental Rinse and chlorhexidine gluconate on feldspathic porcelain.

REFERENCES

1. Featherstone JD, Adair SM, Anderson MH, Berkowitz RJ, Bird WF, Crall JJ, et al. Caries management by risk assessment: consensus statement, April 2002. J Calif Dent Assoc 2003;31:257-69.
2. Featherstone JD. The caries balance: contributing factors and early detection. J Calif Dent Assoc 2003;31:129-33.
3. Takemoto S, Hattori M, Yoshinari M, Kawada E, Asami K, Oda Y. Corrosion mechanism of Ti-Cr alloys in solution containing fluoride. Dent Mater 2009;25:467-72.
4. Wunderlich RC, Yaman P. In vitro effect of topical fluoride on dental porcelain. J Prosthet Dent 1986;55:385-8.
5. Jones DA. Effects of topical fluoride preparations on glazed porcelain surfaces. J Prosthet Dent 1985;53:483-4.
6. Sposetti VJ, Shen C, Levin AC. The effect of topical fluoride application on porcelain restorations. J Prosthet Dent 1986;55:677-82.
7. Butler CJ, Masri R, Driscoll CF, Thompson GA, Runyan DA, Anthony von Fraunhofer J. Effect of fluoride and 10% carbamide peroxide on the surface roughness of low-fusing and ultra low-fusing porcelain. J Prosthet Dent 2004;92:179-83.
8. Sartori R, Correa CB, Marcantonio E Jr, Vaz LG. Influence of a fluoridated medium with different pHs on commercially pure titanium-based implants. J Prosthodont 2009;18:130-4.
9. Correa CB, Pires JR, Fernandes-Filho RB, Sartori R, Vaz LG. Fatigue and fluoride corrosion on *Streptococcus mutans* adherence to titanium-based implant/component surfaces. J Prosthodont 2009;18:382-7.
10. Anderson MH. A review of the efficacy of chlorhexidine on dental caries and the caries infection. J Calif Dent Assoc 2003;31:211-4.
11. van Rijkom HM, Truin GJ, van't Hof MA. A meta-analysis of clinical studies on the caries-inhibiting effect of chlorhexidine treatment. J Dent Res 1996;75:790-5.
12. Kanellis MJ. Caries risk assessment and prevention: strategies for Head Start, Early Head Start, and WIC. J Public Health Dent 2000;60:210-20.
13. Bader JD, Shugars DA, Bonito AJ. A systematic review of selected caries prevention and management methods. Community Dent Oral Epidemiol 2001;29:399-411.
14. Eriksen HM, Nordbo H, Kantanen H, Ellingsen JE. Chemical plaque control and extrinsic tooth discoloration. A review of possible mechanisms. J Clin Periodontol 1985;12:345-50.
15. Watts A, Addy M. Tooth discolouration and staining: a review of the literature. Br Dent J 2001;190:309-16.
16. Al-Marzok MI, Al-Azzawi HJ. The effect of the surface roughness of porcelain on the adhesion of oral *Streptococcus mutans*. J Contemp Dent Pract 2009;10:E017-24.
17. Kawai K, Urano M, Ebisu S. Effect of surface roughness of porcelain on adhesion of bacteria and their synthesizing glucans. J Prosthet Dent 2000;83:664-7.
18. Kantorski KZ, Scotti R, Valandro LF, Bottino MA, Koga-Ito CY, Jorge AO. Surface roughness and bacterial adherence to resin composites and ceramics. Oral Health Prev Dent 2009;7:29-32.
19. Bollen CM, Lambrechts P, Quirynen M. Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: a review of the literature. Dent Mater 1997;13:258-69.
20. Quirynen M, Bollen CM, Papaioannou W, Van Eldere J, van Steenberghe D. The influence of titanium abutment surface roughness on plaque accumulation and gingivitis: short-term observations. Int J Oral Maxillofac Implants 1996;11:169-78.
21. Daulat C. Titanium in today's dental practice. What cuts it? J Prosthodont 2000;9:176-7.
22. Addy M, Loyn T, Adams D. Dentine hypersensitivity—effects of some proprietary mouthwashes on the dentine smear layer: a SEM study. J Dent 1991;19:148-52.
23. Addy M, Absi EG, Adams D. Dentine hypersensitivity. The effects in vitro of acids and dietary substances on root-planed and burred dentine. J Clin Periodontol 1987;14:274-9.
24. Prati C, Montebugnoli L, Suppa P, Valdre G, Mongiorgi R. Permeability and morphology of dentin after erosion induced by acidic drinks. J Periodontol 2003;74:428-36.
25. Soares LE, Cortez LR, Zarur RD, Martin AA. Scanning electron microscopy and roughness study of dental composite degradation. Microsc Microanal 2012;18:289-94.
26. Rawson RD, Bowers M, Beauregard D, Noorda J, Peressini B, Peressini M. SEM and reflectometric evaluation of the effects of fluoride on porcelain. Dent Hyg (Chic) 1984;58:442-5.

Corresponding author:
Dr Radi Masri
6th Floor – Room 6253
650 W Baltimore St
Baltimore, MD 21201
Email: rmasri@umaryland.edu

Acknowledgments
The authors thank Biomet 3i for supplying the titanium bars that were used in this study.