The effect of one-step and multi-step polishing systems on the surface roughness and microhardness of novel resin composites

Ugur Erdemir[1]
Hande Sar Sancakli[1]
Esra Yildiz[1]

ABSTRACT

Objectives: The objective of this in vitro study was to evaluate the surface roughness and microhardness of three novel resin composites containing nanoparticles after polishing with one-step and conventional multi-step polishing systems.

Methods: A total of 126 specimens (10 X 2 mm) were prepared in a metal mold using three nanocomposites (Filtek Supreme XT, Ceram-X, and Grandio), 21 specimens of each resin composite for both tests (n=63 for each test). Following light curing, seven specimens from each group received no polishing treatment and served as controls for both tests. The specimens were randomly polished using PoGo and Sof-Lex systems for 30 seconds after being wet-ground with 1200-grit silicon carbide paper. The mean surface roughness of each polished specimen was determined with a profilometer. The microhardness was determined using a Vickers hardness measuring instrument with a 200-g load and 15 seconds dwell time. The data were analyzed using the Kruskal-Wallis test and the post hoc Dunn's multiple comparison tests at a significance level of .05.

Results: Among all materials, the smoothest surfaces were obtained under a matrix strip (control) (P<.05). There were no statistically significant differences among polishing systems in the resin composites for surface roughness (P>.05). The lowest hardness values for the three resin composites were obtained with a matrix strip, and there was a statistically significant difference compared with other polishing systems (P<.05) whereas no statistically significant differences were observed between the polishing systems (P>.05).

Conclusion: The current one-step polishing system appears to be as effective as multi-step systems and may be preferable for polishing resin composite restorations. (Eur J Dent 2012;6:198-205)

Key words: Polishing systems; surface roughness; microhardness; nanocomposites

INTRODUCTION

Resin composites are widely used for the direct restoration of both anterior and posterior teeth because of the simple bonding procedures, esthetic demands by the patients, and improved physical and mechanical properties of these materials.[1] One of the most significant advances in the last

[1] Department of Restorative Dentistry and Endodontics, Faculty of Dentistry, Istanbul University, Istanbul, TURKIYE

Corresponding author: Dr. Ugur Erdemir
Istanbul Universitesi, Dishekimligi Fakultesi,
Restoratif Dishekimligi ve Endodonti AD. 34093 Capa,
Istanbul, TURKIYE
Tel: + 90 212 4142020 Fax: + 90 212 5250075
E-Mail: uerdemir@hotmail.com

few years is the application of nanotechnology to resin composites. Nanotechnology produces functional materials and structures in the range of 1 to 100 nanometers using various physical and chemical methods. These novel resin composites, which contain nanoparticles, have improved filler technology, modified organic matrixes, and offer a greater degree of polymerization that improves their mechanical and physical properties.[2,3]

Regardless of the cavity class and location, a smooth surface finish is clinically important, as it determines the esthetics and longevity of composite restoration.[1] A rough surface has a major impact on the aesthetic appearance and discoloration of a restoration,[4-6] plaque accumulation, secondary caries, gingival irritation,[7,8] and wear of opposing and adjacent teeth.[9] Furthermore, a smooth surface adds to the patient's comfort, as a change in surface roughness of 0.3 µm can be detected by the tip of the tongue.[10]

The intrinsic characteristics of resin-based composite materials, such as hardness and strength, are crucial mechanical properties that provide a clinically successful restorative material.[11] Hardness, defined as the resistance of a material to indentation, is an important mechanical property that predicts the degree of cure of restorative materials.[11,12] Restorations that are not properly polymerized may result in a softer surface that will retain the scratches created by the finishing procedures. These scratches can compromise fatigue strength and lead to the premature failure of a restoration.[13]

The smoothest composite surface is obtained under a polyester matrix film.[14-17] However, the removal of this surface by the usually required finishing procedures will produce a harder, more resistant, and esthetically acceptable surface.[17]

Finishing is defined as the gross contouring or reduction of a restoration to obtain ideal anatomy. Polishing refers to the reduction of roughness and scratches created by finishing instruments. A variety of instruments, such as carbide and diamond burs, abrasive finish strips, and polishing pastes are frequently used to finish tooth-colored restorative materials.[9,14] Clinicians can choose among a wide range of finishing and polishing instruments. Several studies have demonstrated that multi-step aluminum oxide, graded, abrasive, flexible finishing and polishing discs produce the best surface smoothness.[9,18,19] Many attempts have been made to develop composite finishing instruments and one-step polishing systems for resin composites. Contouring, finishing, and polishing procedures can be completed using a single instrument, and it appears to be as effective as multi-step systems for polishing dental composites.[5,20]

The purpose of the present study was to investigate the surface roughness and microhardness of three novel resin composites containing nanoparticles after polishing with one-step and conventional multi-step polishing systems. The null hypotheses tested were that there would be no difference in surface roughness or microhardness (1) among the polished resin composites or (2) among the different polishing systems when used on the same resin composites.

MATERIALS AND METHODS

Materials and Preparation of the Specimens

Three nanocomposites were used in this study: Filtek Supreme XT (3M ESPE, St. Paul, MN, USA), Ceram X (Dentsply, DeTrey, Konstanz, Germany), and Grandio (Voco, Cuxhaven, Germany). The properties of these materials are shown in Table 1. The finishing and polishing systems evaluated were PoGo (Dentsply/Caulk, Milford, DE, USA) and Sof-Lex discs (3M ESPE, St Paul, MN, USA). Table 2 shows the composition and manufacturers of the polishing systems tested.

A total of 126 specimens were fabricated for both tests (n=63 for each test) using a cylindrical metallic mold (10 mm in diameter and 2 mm thick). Each material was inserted into a cylindrical metal mold and confined between two opposing transparent matrix strips. A glass microscope slide (1 mm in thickness) was then placed on the mold, and a constant pressure was applied to extrude the excess material. All the restorative materials were polymerized according to the manufacturers' recommended polymerization times (20 s) with a halogen light-curing unit (VIP; Bisco Inc., Schaumburg, IL, USA) operating in standard mode and emitting no less than 600 mW/cm^2 as measured with a light meter placed on the curing unit before beginning the polymerization. The guide of the light-curing unit was placed perpendicular to the specimen's surface at a distance of 1 mm. Immediately after the light curing, the specimens were removed from the mold and immersed in distilled water at 37°C for 7 days prior to the finishing procedures.

To reduce variability, all specimen preparations and finishing and polishing procedures were performed by the same investigator. The specimens were randomly divided into three treatment groups (n=7). The matrix strip groups were selected, and others were wet-ground with 1200-grit silicon carbide abrasive paper (SiC) on a rotary polisher (Buehler Metaserv, Buehler, Germany) to provide a baseline before using the polishing systems.

Group I (control group) was made up of specimens that received no finishing or polishing treatment.

Group II (PoGo group), the specimens were polished with diamond micropolisher discs under dry conditions with light hand pressure using a planar motion for 30 seconds at 15,000 rpm using a slow-speed hand piece.

Group III (Sof-Lex group), the specimens were sequentially polished with medium, fine, and super-fine aluminum oxide-impregnated discs under dry conditions with light hand pressure for 30 seconds. After each polishing step, the specimens were thoroughly rinsed with water for 10 seconds to remove debris, air-dried for 5 seconds, and then polished with another disc of lower grit for the same period of time until final polishing. For each specimen, a new polishing disc and a new polisher were used and discarded after each use.

Surface Roughness Test

Following polishing, the specimens were washed, allowed to dry, and stored in distilled water for 7 days before measuring the mean surface roughness (Ra) values. The Ra value of each specimen was measured 5 times, and the mean Ra values were determined with a cut-off value of 0.8 mm, a transverse length of 0.8 mm, and a stylus speed of 0.1 mm/seconds near the center of each specimen using a surface profilometer (Taylor Hobson Surtronic 3^+, Taylor Hobson Ltd., Leicester, England), which was calibrated to meet the standards before each new measuring session.

Microhardness Test

The microhardness was determined using a Vickers hardness measuring instrument (Micromet 5114; Buehler, Lake Bluff, IL, USA). Three indentations were recorded at different points on each specimen no closer than 1 mm to the adjacent indentations with a 200-g load for a 15-s dwell time, and the average value was converted into a Vickers hardness number (VHN).

Table 1. Descriptive table of the resin composites used in the study according to the manufacturer's data.

Material (Manufacturer)	Type	Matrix	Average particle size	Filler type	Filler loading		Shade
					vol (%)	wt (%)	
Filtek Supreme XT (3M ESPE, St. Paul, MN, USA)	Nanofilled composite	Bis-GMA, TEGDMA, UDMA, bisphenol A Polyethylene glycol diether dimethacrylate	0.6-1.4 µm 20 nm	zirconia/silica cluster filler Nanofillers (SiO_2)	59.5	78.5	A2B
Ceram-X (Dentsply, DeTrey, Konstanz, Germany)	Nanohybrid composite	Methacrylate modified ploysiloxane, dimethacylate resin, fluorescent pigment, UV stabilizer, CQ, ethyl-4 (dimethylamino) benzoate, iron dioxide, pigments, aluminum sulfo silicate pigments	1.1–1.5 µm; silica: 0.02 µm	Barium-aluminum-borosilicate glass	57	76	A2
Grandio (Voco, Cuxhaven, Germany)	Nanohybrid composite	Bis-GMA, dimethacrylate, UDMA, TEGDMA	1 µm 20-50 nm	Ba-Al-borosilicate glass filler Nanofiller (SiO_2)	71.4	87	A2

Bis-GMA: Bisphenol A diglycidyl ether dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; UDMA: urethane dimethacrylate; CQ: camphorquinone

Table 2. The composition and manufacturers of the polishing systems investigated.

Polishing System	Composition	Manufacturers
PoGo (One-step)	Polymerized urethane dimethacrylate resin, fine diamond powder, silicon oxide (20 µm)	Dentsply/Caulk, Milford, DE, USA)
Sof-Lex Pop-On Discs (Multi-step)	Aluminum oxide-coated disk medium (40 µm) fine (24 µm) ultra-fine (8 µm)	3M ESPE, St. Paul, MN, USA

Statistical Analysis

Statistical analysis was performed using the 2007 version of the NCSS-PASS statistical software package (Kaysville, Utah, USA). As the average roughness and microhardness values were not normally distributed (Kolmogorov-Smirnov test), a non-parametric Kruskal-Wallis analysis of variance was applied to assess significant differences among the experimental groups. Dunn's multiple comparison was applied for post-hoc comparisons. The statistical significance level was established at $P<.05$.

RESULTS

Surface Roughness Test Results

The mean surface roughness (Ra) values and standard deviation produced by the matrix strips, PoGo, and Sof-Lex discs on three resin-based composites are listed in Table 3 and Figure 1. For all materials, the smoothest surfaces were obtained under matrix strip (control) rather than the polishing systems tested ($P<.05$). There were no statistically significant differences between PoGo and Sof-Lex for the Filtek Supreme XT, Ceram X, and Grandio groups ($P>.05$). In the Filtek Supreme XT and Ceram-X groups, Sof-Lex produced higher roughness values than the PoGo with no statistically significant difference. On the other hand, in the Grandio group, PoGo produced higher roughness values than the Sof-Lex, but the difference was statistically insignificant.

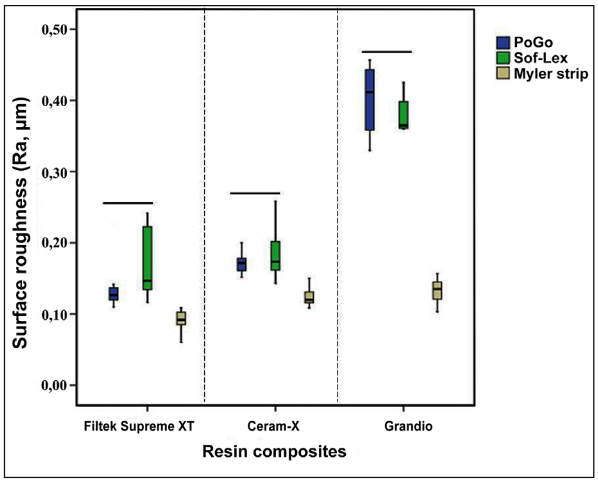

Figure 1. Surface roughness of the resin composites tested. Polishing systems with the same black bar are not statistically different.

For the matrix strip groups, Filtek Supreme XT had the smoothest surface, which was significantly different from the Ceram-X and Grandio groups ($P<.05$). There were no statistical differences among the specimens in the Ceram-X and Grandio groups ($P>.05$).

For the PoGo groups, Grandio showed a significantly higher surface roughness compared to the other composites ($P<.05$); however, there were no statistically significant differences among Filtek Supreme XT and Ceram-X groups ($P>.05$). For the Sof-Lex group, Grandio showed a significantly higher surface roughness compared to the other composites ($P<.05$); however, there were no statistically significant differences among the specimens in the Filtek Supreme XT and Ceram-X groups ($P>.05$).

Table 3. Mean surface roughness values (Ra, µm) and standard deviations (SD) for the tested resin composite materials and polishing systems.

Groups	Polishing Systems	n	*Ra Values (µm) (Mean±SD)*
Filtek Supreme XT	Mylar Strip	7	0.09±0.02a
	PoGo	7	0.14±0.04b
	Sof-Lex	7	0.17±0.05b
Ceram-X	Mylar Strip	7	0.12±0.01c
	PoGo	7	0.17±0.02d
	Sof-Lex	7	0.19±0.04d
Grandio	Mylar Strip	7	0.13±0.02e
	PoGo	7	0.40±0.05f
	Sof-Lex	7	0.37±0.05f

An intra-group comparison was performed for each polishing system in its own group of restorative materials. The same superscript letters denoted the surface roughness *(Ra)* values represent statistical insignificance whereas different small letters represents statistical significance for the *post hoc* test at the 5% level.

Microhardness Test Results

The mean microhardness values and standard deviations produced by matrix strips, PoGo, and Sof-Lex discs on three resin-based composites are displayed in Table 4 and Figure 2. The lowest hardness values were recorded for the three resin composites under matrix strips, which showed a statistically significant difference compared with other polishing systems tested (P<.05). No statistically significant differences were observed between the polishing systems (PoGo, and Sof-Lex) for all composite groups (P>.05). For all the polishing systems, the ranking for microhardness values from least to greatest were as follows: Ceram-X < Filtek Supreme XT < Grandio (P<.05).

DISCUSSION

In aesthetic dentistry, the restorative material should duplicate the appearance of the natural tooth. A resin composite restoration can be imperceptible to the naked eye when its surface closely resembles the surrounding enamel surface. Therefore, polished restorations should demonstrate an enamel-like surface texture and gloss.[5] The surface quality of resin composite materials affects plaque accumulation,[7,8] physical properties,[11] abrasivity, and wear resistance.[4,6] Surface roughness is associated with patient discomfort in terms of the tactile perception,[10] aesthetic appearance,[4-6] and stain resistance of restorative materials.[5,21] However, resin composite materials cannot be finished to an absolutely smooth surface.

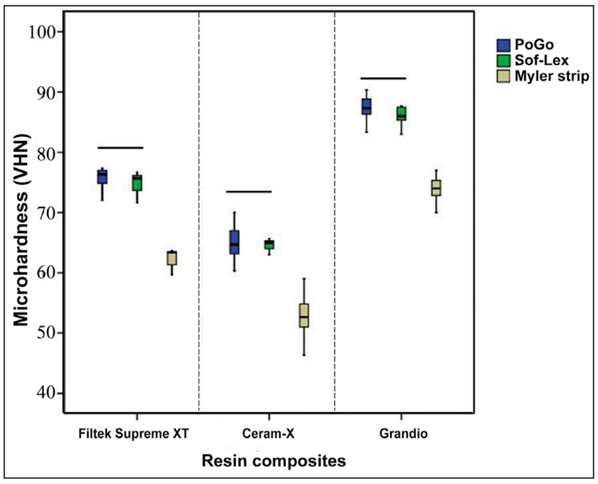

Figure 2. Microhardness values of the resin composites tested. Polishing systems with the same black bar are not statistically different.

In the present study, a matrix strip was used to produce standardized specimens. After light polymerization, the specimens that received no polishing served as controls and were compared with groups treated with different polishing systems. Such samples, cured under matrix strips, have also been used as controls in several studies and, similar to our results, the smoothest surfaces were obtained by curing the resin composite materials against a matrix strip.[1,16,20] The unpolished surfaces of all tested composites were significantly smoother than those of the polished specimens. Filtek Supreme XT exhibited a significantly lower roughness value, while the roughness of the other composites was not significantly different. However, this resin-rich layer on the top had poor physical, mechanical, and biological properties. Therefore, it should be eliminated during the finishing and polishing procedures.[22,23] After the polishing procedures, Filtek Supreme XT and Ceram-X showed the smoothest surfaces with no significant difference among them after both polishing techniques were used in the present study. However, Grandio exhibited significantly higher roughness values after both polishing systems were applied. This observation is in agreement with the results of a previous study[20] that showed no significant difference in surface roughness between Filtek Supreme XT and Ceram-X. This result could be related to the specific composition of Filtek Supreme XT, which contains only nanofillers, which is in the same range as the microfillers. The nano-

Table 4. Mean microhardness values (VHN) and standard deviations (SD) for the tested resin composite materials and polishing systems.

Groups	Polishing Systems	n	Microhardness Values (VHN) (Mean±SD)
Filtek Supreme XT	Mylar Strip	7	62.81±2.47^{a}
	PoGo	7	75.62±1.90^{b}
	Sof-Lex	7	74.81±1.93^{b}
Ceram-X	Mylar Strip	7	52.81±4.03^{c}
	PoGo	7	65.05±3.44^{d}
	Sof-Lex	7	64.62±0.99^{d}
Grandio	Mylar Strip	7	73.90±2.41^{e}
	PoGo	7	87.90±3.51^{f}
	Sof-Lex	7	86.05±1.70^{f}

An intra-group comparison was performed for each polishing system in its own group of restorative materials. The same superscript letters denoted the microhardness *(VHN)* values represent statistical insignificance whereas different small letters represents statistical significance for the *post hoc* test at the 5% level.

hybrid composite material Grandio exhibited the highest surface roughness among the materials examined when it was finished with both finishing and polishing systems. This material contains 1 µm glass ceramic particles in the formulation that might have been left protruding from the surface after the finishing and polishing procedures, which could explain its high roughness values.

Clinically, some functional adjustment is necessary in almost all restorations; thus, in the present study, finishing was carried out with 1200-grit SiC paper under running water to simulate the clinical finishing procedure.[20]

Finishing and polishing procedures require a sequential use of instrumentation to achieve a highly smooth surface.[24] In the present study, a graded abrasive system that ends gradually with a smaller grain size was selected to obtain an optimum surface finish. Also, a one-step polisher, PoGo, was used to achieve a similar goal but with fewer steps and application time. In the present study, a planar motion was used for all specimens, as a previous study demonstrated that this motion produced significantly lower mean surface roughness values.[25]

Marigo et al[24] reported that the final glossy surface obtained by polishing depends on the flexibility of the backing material in which the abrasive is embedded, the hardness of the particles, and the instruments and their geometry (cusp, discs, and cones). For a resin composite restorative material finishing system to be effective, the abrasive particles must be relatively harder than the filler materials. Otherwise, the polishing system will remove only the soft resin matrix and leave the filler particles protruding from the surface.[26] In the present study, PoGo achieved an equally smooth surface compared to Sof-Lex for Filtek Supreme XT and Ceram-X. The superior performance of PoGo may be attributed to the fine diamond powders used instead of aluminum oxide (Sof-Lex) and the cured urethane dimethacrylate resin delivery medium. Diamond is always harder than alumina; thus, it may cause deeper scratches on the surface of the composites, resulting in high roughness.[12,19] However, the reverse was found in this study; PoGo produced a smoother surface on Filtek Supreme XT and Ceram-X, with the difference being statistically insignificant, except with highly filled composite Grandio. This result is in accordance with the findings of previous studies.[5,20] In contrast with the present study results, Ergucu and Turkun[5] found that the PoGo produced an equally smooth surface for Grandio as those for Mylar. However, in the present study, for the Grandio group, Sof-Lex achieved a smoother surface than the PoGo, with no statistically significant difference.

In the present study, PoGo was used as a one-step polishing system, but the manufacturer recommends pre-treatment with the Enhance system to obtain favorable results. Some investigators have used this system as a one-step method without any pre-treatment.[1,5,20] For this reason, the authors of this study applied PoGo as a one-step method.

A clinical study showed that the majority of patients could detect differences of about 0.3 µm in mean roughness.[10] In this study, PoGo and Sof-Lex created roughness values lower than 0.3 µm except with Grandio. This can be attributed to the fact that the effectiveness of polishing systems is dependent on the material, as previously described.[1,5] The capacity of disks impregnated with aluminum oxide particles to achieve smooth surfaces is related to their ability to equally remove particles and organic matrix. However, these systems have limitations due to geometry. While using the disks, it is often difficult to efficiently create, finish, and anatomically polish the contoured surfaces, specifically in the posterior regions of the mouth.[17]

Profilometers have been used to measure surface roughness in vitro.[5,6,14] Although the profilometers provide limited two-dimensional information, it arithmetically calculates average roughness and is used in making treatment choices because it offers various material/polishing surface combinations.[26,27] However, the complex structure of a surface cannot be fully characterized using surface roughness measurements alone. Therefore, it is not appropriate to draw conclusions regarding the clinical suitability of a finishing instrument exclusively on the basis of roughness average results. However, in combination with atomic force microscopy (AFM) and scanning electron microscopy (SEM) analysis, more valid predictions about clinical performance can be made. In the present study, surface roughness measurements were used only for relative comparisons.

The finishing procedure, as performed in a clinical setting, can also affect the physical properties of resin composites.[28] Examination of removed composite restorations suggests that physio-chemical stresses result in the formation of microcracks, microvoids, or interfacial gaps at the interface between the filler and matrix.[29]

The surface hardness test has been used in many studies since it has been shown to be an indicator of the degree of polymerization.[30] In the present study, to obtain adequate polymerization, all samples were polymerized according to the manufacturers' instructions using a halogen curing light.

The factors significantly affecting the hardness values of restorative materials include the filler volume fraction, composition, resin type, and polymerization degree. After polymerization, monomers that do not participate in reactions lead to a decrease in hardness, and the hardness of the inorganic fillers directly affects the overall hardness of the materials. Researchers have reported that increased inorganic filler levels result in increased hardness values for resin composites.[31] In the present study, the surface created with a Mylar strip exhibited statistically lower microhardness values than those produced by all polishing systems. This finding is also in agreement with a recently published study on resin composites' microhardness.[20]

The present study's results showed that significantly higher microhardness values were achieved with Grandio than with the other resin composites, which had the highest filler content (87% by weight). Similarly, a recently published study conducted by Cekic-Nagas et al[32] evaluated the Vickers hardness of five resin composites and correlated the higher Vickers microhardness test values of Grandio with its filler contents by weight and organic matrix composition. No other significant difference in hardness was observed among the different polishing systems tested in all the composite groups.

Further studies are needed to determine which finishing technique is best suited to clinical situations where access is limited, restoration surfaces are not flat, and AFM and SEM analyses are not available to obtain more valid results.

CONCLUSION

Within the limitations of the present study, the first null hypothesis tested, that there would be no difference in surface roughness or microhardness among the polished resin composites, was rejected. The nanofil (Filtek Supreme XT) and nanohybrid (Ceram-X) resin composites showed smoother surfaces and lower microhardness than the nanohybrid (Grandio) resin composite regardless of the polishing system used. The second null hypothesis tested, that there would be no difference in surface roughness or microhardness among the different polishing systems when used on the same resin composites, was accepted. One-step (PoGo) and multi-step (Sof-Lex) polishing procedures produced similar quality in terms of surface roughness and microhardness on the same resin composites evaluated. One- and multi-step polishing procedures decreased the smoothness obtained with matrix strips; however, both systems resulted in Ra values below the threshold value of 0.3 μm, except for Grandio.

Considering the reduced number of steps, the current one-step polishing system appears to be as effective as multi-step systems and may be preferable for polishing resin composite restorations.

REFERENCES

1. Yap AU, Yap SH, Teo CK, Ng JJ. Finishing/polishing of composite and compomer restoratives: Effectiveness of one-step systems. *Oper Dent* 2004;29:275-279.
2. Mitra SB, Wu D, Holmes BN. An application of nanotechnology in advanced dental materials. *J Am Dent Assoc* 2003;134:1382-1390.
3. Beun S, Glorieux T, Devaux J, Vreven J, Leloup G. Characterization of nanofilled compared to universal and microfilled composites. *Dent Mater* 2007;23:51-59.
4. Cavalcante LM, Masouras K, Watts DC, Pimenta LA, Silikas N. Effect of nanofillers' size on surface properties after toothbrush abrasion. *Am J Dent* 2009;22:60-64.
5. Ergucu Z, Turkun LS. Surface roughness of novel resin composites polished with one-step systems. *Oper Dent* 2007;32:185-192.
6. Kakaboura A, Fragouli M, Rahiotis C, Silikas N. Evaluation of surface characteristics of dental composites using profilometry, scanning electron, atomic force microscopy and gloss-meter. *J Mater Sci Mater Med* 2007;18:155-163.

7. 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;13:258-269.
8. Ono M, Nikaido T, Ikeda M, Imai S, Hanada N, Tagami J, Matin K. Surface properties of resin composite materials relative to biofilm formation. *Dent Mater* J 2007;26:613-622.
9. Jefferies SR. Abrasive finishing and polishing in restorative dentistry: a state-of-the-art review. *Dent Clin North Am* 2007;51:379-397.
10. Jones CS, Billington RW, Pearson GJ. The in vivo perception of roughness of restorations. *Br Dent J* 2004;196:42-45.
11. Gordan VV, Patel SB, Barrett AA, Shen C. Effect of surface finishing and storage media on bi-axial flexure strength and microhardness of resin-based composite. *Oper Dent* 2003;28:560-567.
12. O'Brien WJ. Physical properties in dental materials and their selection. Illinois, Quintessence Publishing Co., 4th ed., 2008, p. 18.
13. Ferracane JL, Mitchem JC, Condon JR, Todd R. Wear and marginal breakdown of composites with various degrees of cure. *J Dent Res* 1997;76:1508-1516.
14. Attar N. The effect of finishing and polishing procedures on the surface roughness of composite resin materials. *J Contemp Dent Pract* 2007;8:27-35.
15. Senawongse P, Pongprueksa P. Surface roughness of nanofill and nanohybrid resin composites after polishing and brushing. *J Esthet Restor Dent* 2007;19:265-275.
16. Baseren M. Surface roughness of nanofill and nanohybrid composite resin and ormocer-based tooth-colored restorative materials after several finishing and polishing procedures. *J Biomater Appl* 2004;19:121-134.
17. Turkun LS, Turkun M. The effect of one-step polishing system on the surface roughness of three esthetic resin composite materials. *Oper Dent* 2004;29:203-211.
18. Barbosa SH, Zanata RL, Navarro MF, Nunes OB. Effect of different finishing and polishing techniques on the surface roughness of microfilled, hybrid and packable composite resins. *Braz Dent J* 2005;16:39-44.
19. Lu H, Roeder LB, Lei L, Powers JM. Effect of surface roughness on stain resistance of dental resin composites. *J Esthet Restor Dent* 2005;17:102-109.
20. Korkmaz Y, Ozel E, Attar N, Aksoy G. The influence of one-step polishing systems on the surface roughness and microhardness of nanocomposites. *Oper Dent* 2008;33:44-50.
21. Patel SB, Gordan VV, Barrett AA, Shen C. The effect of surface finishing and storage solutions on the color stability of resin-based composites. *J Am Dent Assoc* 2004;135:587-594.
22. Morgan M. Finishing and polishing of direct posterior resin restorations. *Pract Proced Aesthet Dent* 2004;16:211-217.
23. Ryba TM, Dunn WJ, Murchison DF. Surface roughness of various packable composites. *Oper Dent* 2002;27:243-247.
24. Marigo L, Rizzi M, La Torre G, Rumi G. 3-D surface profile analysis: Different finishing methods for resin composites. *Oper Dent* 2001;26:562-568.
25. Fruits TJ, Miranada FJ, Coury TL. Effects of equivalent abrasive grit sizes utilizing differing polishing motions on selected restorative materials. *Quintessence Int* 1996;27:279-285.
26. Tjan AH, Chan CA. The polishability of posterior composites. *J Prosthet Dent* 1989;61: 138-146.
27. McLundie AC, Murray FD. Comparison of methods used in finishing composite resin- a scanning electron microscope study. *J Prosthet Dent* 1974;31:163-171.
28. Leinfelder KF, Wilder AD Jr, Teixeira LC. Wear rates of posterior composite resins. *J Am Dent Assoc* 1986;112:829-833.
29. Mair LH. Staining of in vivo subsurface degradation in dental composites with silver nitrate. *J Dent Res* 1991;70:215-220.
30. Asmussen E. Factors affecting the quantity of remaining double bonds in restorative resin polymers. *Scan J Dent Res* 1982;90:490-496.
31. Chung KH. The relationship between composition and properties of posterior resin composites. *J Dent Res* 1990;69:852-856.
32. Cekic-Nagas I, Egilmez F, Ergun G. The effect of irradiation distance on microhardness of resin composites cured with different light curing units. *Eur J Dent* 2010;4:440-446.