Original Article

Surface roughness and microhardness evaluation of composite resin restorations subjected to three different polishing systems immediately and after 24 h: An *in vitro* study

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Abstract

Background: Finishing and polishing of composite resin restorations can be considered two different procedures or two steps of a single procedure. During the finishing procedure, contours are corrected while margins and irregularities are smoothened. The polishing procedures result in the production of a smooth and lustrous finish. Consensus regarding the correct timing for initiating the steps of finishing and polishing after the curing of the composite resins is divided. Some authors support immediate finishing and polishing while other authors support delaying the finishing and polishing procedures.

Aim: The aim of this study is to evaluate the surface roughness and microhardness of composite resin restoration subjected to finishing and three different polishing systems immediately and after 24 h.

Materials and Method: Eighty composite resin samples were prepared. A Teflon mold was made which was customized for this study having dimensions of 10-mm diameter and 2-mm depth. For the first group of specimens, Group I ($n = 20$) the composite resin surface was covered with Mylar Strips which acted as control. The other specimens ($n = 60$) were prepared without the use of a Mylar strip, followed by curing. For all the samples, curing was done with a light-emitting diode for 40 s each. Eighty light-cured samples were divided equally into 4 groups, each group containing 20 samples ($n = 20$). Out of the 20 samples, in the second, third, and fourth groups, (Kenda C. G. I., Shofu Super-snap X-Treme, and Eve Diacomp Plus Twist) 10 samples were finished and polished immediately after curing and the other 10 samples were finished and polished after 24 h of curing. The samples in Groups II, III, and IV were subjected to finishing by a 12-fluted tungsten carbide bur and were polished according to the respective manufacturer's instructions. The samples were then subjected to quantitative analysis of surface roughness by a noncontact three-dimensional optical profilometer (Bruker GT-Q; Ettlingen, Germany) and qualitative analysis of surface roughness by a scanning electron microscope (Zeiss EVO 18 Special Edition; Carl-Zeiss-Strasse; Oberkochen Germany) at ×10,000 magnification. The samples were also subjected to Vickers microhardness measurement using a microhardness tester (Leica VMHT 001; Walter UHL GmbH, Germany) under 100 g load over 10 s.

Conclusion: A. For surface roughness: The samples cured under Mylar strips gave the least surface roughness values (0.25 ± 0.032). Immediate finishing and polishing procedures led to statistically less surface roughness than when finishing and polishing procedures were performed after a delay of 24 h for all polishing systems used B. For microhardness: The samples cured under Mylar strips gave the least microhardness values (57.1 ± 2.03). Delayed finishing and polishing increased microhardness values in all finishing and polishing systems used. Different polishing systems did not have any significant effect on the microhardness values in immediate and delayed finishing and polishing groups.

Keywords: Composite resin; finishing; microhardness; polishing; surface roughness; three dimensional optical profilometer; timing; Vicker's microhardness

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INTRODUCTION

Finishing and polishing procedures are the main steps that create the shape and texture of the restoration which impart all the three-dimensional (3-D) features that natural teeth possess. Finishing and polishing of restorations are desirable not only for esthetic considerations but also for better oral health.[1]

These procedures help in preventing rough surfaces in the oral cavity which may contribute to microorganism retention.[2] They also help in achieving proper occlusions and desired anatomy which make the restorations seem seamless. A polished surface is more biologically compatible with the gingival tissues as it reduces the likelihood of adhesion of plaque. The smoother surface of the composite resin restorations leads to a lesser light scattering effect and a higher gloss of the material.

Evidence shows that the surface roughness of composite resins is affected by various intrinsic and extrinsic factors. Factors such as the type, shape, size, and distribution of filler particles, the type of resin matrix, and the effectiveness of the bond between the filler and the matrix[3] constitute the intrinsic factors.

Extrinsic factors affecting the surface roughness of composite resins are the type of finishing and polishing instruments, the hardness of the abrasive particles, and the discs' flexibility.

With hybrid composites, finishing diamonds have been shown to produce rough, trough-like surfaces compared to carbide burs. According to Daud *et al*.,[4] tungsten carbide burs provide a smoother finishing surface than diamond finishing burs. Therefore, in this study, 12 fluted tungsten carbide burs have been used for finishing the microhybrid composite resin (Te-Econom Plus).

Shofu Super-snap X-Treme system (Shofu) is a polishing system that consists of aluminum oxide discs and is a four-step polishing system. The disc shape of the polishers with 3-D X-tra coating on the red superfine discs allows space for ground debris discharge and reduces heat generated without any denaturation of the material.

Kenda polishing system (Coltene Whaledent) is a polishing system consisting of silicon carbide and aluminum oxide abrasives embedded in either silicon or synthetic rubber. It is a three-step color-coded polishing system.

Eve Diacomp Plus Twist (Ivoclar Vivadent) is a two-step polishing system with diamond abrasive particles impregnated in rubber. It is available in the form of spirals of two colors. The lamellar surface of the wheel adapts to the surface structure, which means that the use of different geometries of polishers for different surfaces is no longer mandatory.

According to O'Brien WJ, hardness can be defined as the "resistance of a material to indentation."[5] 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 the fatigue strength of the restoration and lead to premature failures.[6] According to Dejan Marković, microhardness or indentation hardness is defined as the hardness of the material exposed to low applied loads under 10 N.[7] Microhardness is an indirect measure of the degree of conversion of a material.

In literature, polishing methods or procedures are well documented, but the timing, i.e., immediate or delayed finishing and polishing which might affect the physical properties of the resin is less investigated. The existing literature shows controversy regarding whether immediate or delayed polishing should be done with authors reaching contrasting conclusions.[8-10]

There is an ever-evolving market for polishing systems with new systems being introduced in recent times. Hence, continuous evaluation of different systems regarding their efficacy is clinically relevant. To the best of our knowledge, no studies have compared the efficacy of Kenda C. G. I, Shofu Super-snap X-Treme, and EVE Diacomp Plus Twist with each other regarding their effect on the surface roughness and microhardness of composite resins in a single study.

The aim of this study is to evaluate the surface roughness and microhardness of composite resin restoration subjected to one standardized finishing and three different polishing systems immediately and after 24 h.

The null hypothesis states that:

1. There will be no difference in surface roughness of composite resin restorations when finishing and polishing are done immediately and after 24 h and by different polishing systems
2. There will be no difference in microhardness of composite resin restorations when finishing and polishing are done immediately and after 24 h and by different polishing systems.

MATERIALS AND METHODS

Sample size estimation

Sample size estimation was done using GPower software (version 3.0). A minimum total sample size of 80 (20 per group) was sufficient for an alpha of 0.05, power of 80%, and 0.40 as effect size (assessed for the difference in surface roughness and microhardness from similar articles).

Sample preparation

First, a Teflon mold was created using a Teflon pipe (Star Polymer) which had an internal diameter of 10 mm creating a Teflon mold with dimensions of 10 mm (diameter) and 2 mm (height). This Teflon mold was then placed on a glass slab. The composite resin material was filled incrementally (2 increments of 1 mm each to ensure adequate polymerization of each increment[11]) in the Teflon mold with a titanium-coated two-sided flat-ended composite resin filling instrument.

For the control group, after the mold was slightly overfilled with composite resin, a Mylar strip followed by another glass slab was placed on the top surface and lightly pressed to extrude the excess composite resin. The glass slab was then removed, and curing was done through the Mylar strip. For the other groups, curing was done directly after the mold was filled fully with the composite resin. The specimens were subjected to curing by placing the nozzle tip of the curing unit (10 mm diameter) on the upper surface mold with a light-emitting diode light (Elipar S10, 3M Oral Care, St. Paul, MN, USA) for 40 s each. The light-curing unit had an irradiance of 1400 Mw/cm^2 and the tip was placed directly contacting the top surface of the sample in those cured without the Mylar strip and was placed at 1 mm from the sample in case of the control group due to the thickness of the Mylar strip. After curing, the samples were removed from the Teflon mold.

Finishing of samples

Except for samples in Group I (control), the other samples were subjected to finishing (half of them immediately, the other half 24 h after curing) by a 12-fluted tungsten carbide bur attached to a high-speed air rotor handpiece (NSK, Japan) for 15 s under water cooling. The tungsten carbide burs were changed after every three samples.[12] The samples were subsequently subjected to polishing.

Polishing of samples

Groups II, III, and IV were polished. It was carried out in a planar motion to produce the lowest surface roughness,[13] at a speed of 10,000 Rpm for standardization. The polishing devices were in constant motion since the movement prevented heat generation and the creation of grooving.[14] Light, intermittent, and repetitive strokes were used. The systems were used in the same way (10 strokes and 20 s for each step) to permit comparison among them.[15]

Group II: Polishing was done with the Kenda C. G. I. polishing system (KI).

A. Immediately after curing
B. 24 h after curing.

Group III: Polishing was done with the Shofu Super-snap X-Treme polishing system (SS).

A. Immediately after curing
B. 24 h after curing.

Group IV: Polishing done with the EVE Diacomp Plus Twist polishing system (ED).

A. Immediately after curing
B. 24 h after curing.

Surface roughness analysis

A noncontact 3-D optical profilometer (Contour GT-K; Bruker Schwarzschildstrasse, Berlin, Germany) was used to measure the mean surface roughness (Ra - defined as the arithmetic mean deviation from the center line of a surface) of the samples. Three linear horizontal measurements were taken in the initial and final areas in composite resin. The Ra value for all groups was calculated as $Ra = Ra_{final} - Ra_{initial}$.

Surface texture analysis

The surfaces of the samples were examined under SEM (Zeiss EVO 18 Special Edition; Carl-Zeiss-Strasse; Oberkochen Germany) at ×10,000 to investigate the surface morphology. The samples were sputter-coated with platinum (10 nm thickness) to aid conductivity. It worked at an operating voltage of 15 kV providing a spatial resolution of up to 1 μm.

Vicker's microhardness testing

Vickers microhardness was conducted on a Leica VMHT 001 (Walter UHL GmbH, Germany) microhardness tester under 100 g load, over 10 s. Four indentations were made on each specimen, one in each quadrant, equidistant from the center. The readings were recorded immediately after the removal of the penetrator to minimize the effect of elastic recovery. The mean of the four indentations was used to determine the Vickers hardness number of each specimen.

RESULTS

Surface roughness

Intragroup comparison of surface roughness between Kenda C. G. I., Shofu Super-snap Extreme, and EVE Diacomp Plus Twist specimens was done using paired *t*-test. The mean surface roughness score of the delayed finishing and polishing subgroup was found to be significantly high as compared to that of the immediate finishing and polishing subgroup in all three systems ($P < 0.001$).

One-way analysis of variance (ANOVA) and posthoc Tukey's tests were done. Intergroup comparison of surface roughness in immediate and delayed finishing and polishing (Graph 1 and Graph 2 respectively) was done using one-way ANOVA test and revealed statistical significance ($P < 0.001$).

Microhardness

Intragroup comparison of microhardness between Kenda C. G. I, Shofu Super-snap Extreme, and EVE Diacomp Plus Twist specimens was done using paired *t*-tests. The mean microhardness score of the delayed finishing and polishing subgroup was found to be high as compared to that of the immediate finishing and polishing subgroup ($P = 0.028$, $P < 0.001$, $P = 0.143$). The mean microhardness score was found to be statistically significant in the first two groups.

One-way ANOVA and posthoc Tukey's tests were performed. Intergroup comparison of microhardness in immediate and delayed type (Graph 3 and Graph 4 respectively) was done using one-way ANOVA test and revealed statistical significance ($P < 0.001$). The mean immediate and delayed microhardness scores of control were found to be significantly low as compared to that of Kenda C.G.I., Shofu Super-snap Extreme, and EVE Diacomp Twist Plus.

DISCUSSION

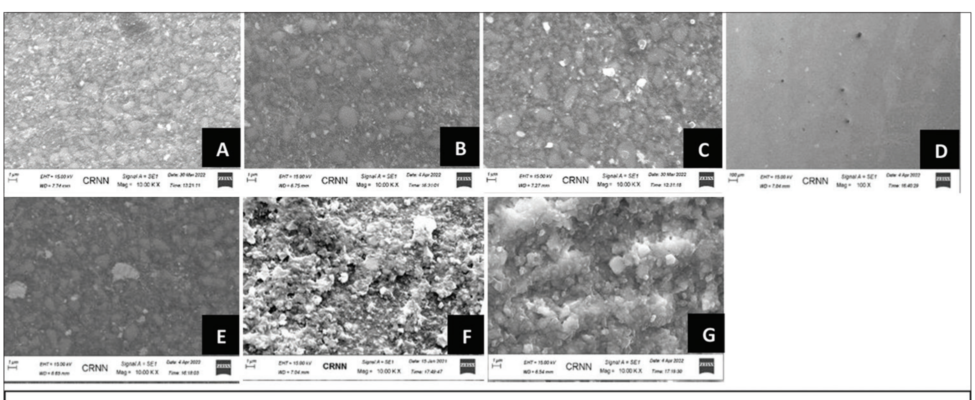
Finishing allows for the creation of proper anatomy and occlusal morphology of the restoration, whereas polishing allows the elimination of scratches and a reduction in surface roughness.[16] Finishing and polishing are important procedures because well-contoured and polished surfaces prevent the deposition of dental plaque and residues, which damages the soft tissue and periodontium.

Microhybrid composites contain both macro- and micro-sized particles with a mean size of <1 μm and microfilters with an approximate size of 0.04 μm. Furthermore, they have a more uniform filler load distribution which makes them easier to light cure.[17] These factors give the resin composites both reliable mechanical properties (handling, wear, and strength) as well as a greater polishing capacity producing surfaces similar to natural teeth.[18]

In the present study, it was found that the control group, in which the samples were cured against the Mylar strip produced the lowest surface roughness values as found in previous studies.[15,19-21] When resin composite surface contacts with finishing and polishing systems, hard filler particles are abraded away from the resin matrix leading to comparatively increased surface roughness.[9,22] Although the smoothest surface of resin composite is achieved under a Mylar strip, this surface cannot be maintained clinically because no flat tooth surface exists. The complex tooth morphology will necessitate the clinician to finish and polish the restoration to reassemble it.

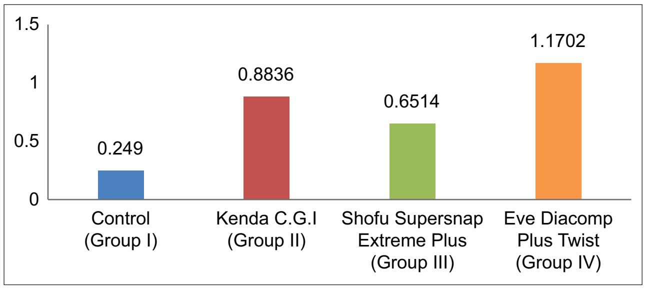
The present study shows that immediate finishing and polishing of the composite resin samples have given statistically significant lower roughness values than the samples finished and polished after a delay of 24 h, analyzed quantitatively [Table 1] and qualitatively [Figure 1]. This result corresponds to studies by Madhyastha *et al.*,[8] Kaminedi *et al.*,[20] and Venturini *et al*.[15] recommending immediate polishing. At the glass transition temperature (Tg), there is a transition from a rigid state to a more flexible state, whereas at temperatures below Tg, the material shows rigid and brittle behavior.[23]

The composite is 75% polymerized after light-curing[24] and it continues over a period of 24 h. An incomplete

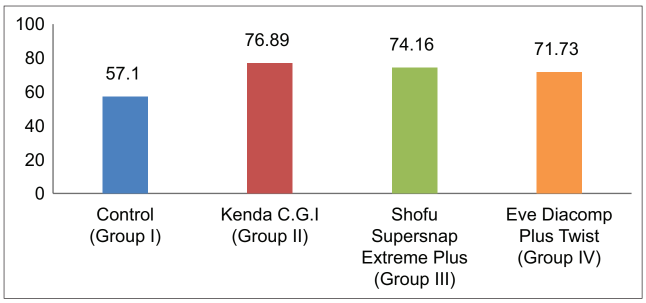


A- Control: The irregular shape of filler particles along with their size variation of larger and smaller filler particles is observed. The shape and size of the filler particles allow for the dense arrangement of filler particles.
B- Kenda C.G.I. Immediate: The shape, size of the filler particles, and the presence of dislodged particles are observed.
C- Kenda C.G.I 24 Hours: The shape, size of the filler particles, and the presence of more dislodged particles are observed.
D- Shofu SuperSnap Extreme Immediate: Homogenous surfaces with isolated areas showing nodules over a wider area are observed, they might be representative of areas of melting and subsequent solidification as was observed in a study by C.L. Davidson et. Al
E- Shofu SuperSnap Extreme 24 Hours: The uniform abrasion of the filler particles with more dislodged particles is observed.
F- Eve Diacomp Plus Twist Immediate: The surface is non-homogenous with areas showing filler particles that have been plucked out of the resin matrix.
G- Eve Diacomp Plus Twist 24 Hours: The surface is non-homogenous with areas showing filler particles that have been plucked out of the resin matrix resulting in the formation of voids.

Figure 1: SEM Analysis of groups at 10,000 X magnification (Qualitative Analysis)



Graph 1: Intergroup comparison of surface roughness (immediate)



Graph 3: Intergroup comparison of microhardness (immediate)

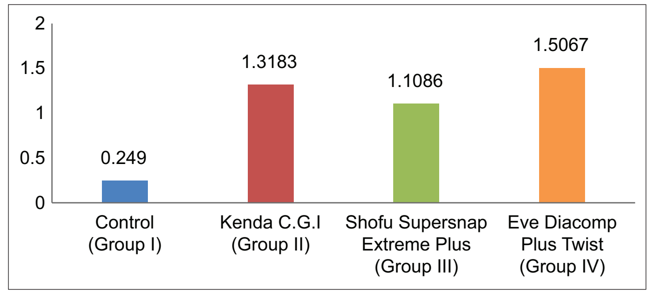
Table 1: Profilometer Analysis

Group analysed	Value (μm)
Control	0.249
Shofu Super-snap X-Treme immediate	0.63
Shofu Super-snap X-Treme 24 h	1.03
EVE Diacomp Plus Twist immediate	1.12
EVE Diacomp Plus Twist 24 h	1.48
Kenda immediate	0.85
Kenda 24 h	1.33

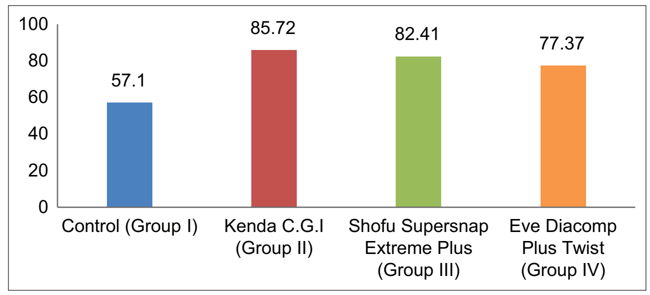
polymerization of the matrix resulted in a low Tg (16°C–58°C) while a completely polymerized composite exhibited higher Tg (130°C–178°C).[25] The heat generated due to frictional forces during immediate finishing and polishing procedures can reach the Tg or exceed it and result in localized softening and melting. This may lead to the smearing of the resin over the exposed filler particles, making the surface smooth.[26]

The results of this study are in agreement with a study by Davidson *et al*.[27] as dry polishing was carried out for all of the polishing systems used. They concluded that, in dental practice, dry polishing at low pressures causes composite surfaces to be covered with a smear layer. This film benefits the performance of the restoration concerning smoothness.

However, some authors such as Yap *et al*.[28] and Mazumdar *et al*.[29] reported that delayed finishing and polishing of polyacid-modified composite resins resulted in a smoother surface.



Graph 2: Intergroup comparison of surface roughness (delayed)



Graph 4: Intergroup comparison of microhardness (delayed)

This study finds that Shofu Super-snap X-Treme (SS) produces the smoothest surface, followed by Kenda C. G. I (KI), which is followed by EVE Diacomp Twist Plus (ED). The reasons for the obtained results could be because aluminum oxide abrasives contained in Shofu Super-snap X-Treme and Kenda C. G. I polishing systems have a value of 9 on Moh's scale. The harder diamond abrasives (10 on Moh's scale) may cause deeper scratches on the surface of the composites, resulting in EVE Diacomp Plus Twist having the highest roughness among the group.[30] The use of aluminum oxide discs is best recommended because their malleability promotes a homogenous abrasion of the fillers and the resin matrix.[31] Better results were obtained with the use of the Shofu Super-snap X-Treme polishing system in comparison with that of Kenda C. G. I though both systems contain aluminum oxide might be due to the smaller (SS superfine = 7 μm; KI ultrafine = 8 μm) sizes of abrasives contained in the SS polishing kit.

As there were significant differences in surface roughness of the composite resin samples when finishing and polishing were done immediately and after 24 h ($P < 0.00l$) and by different finishing and polishing systems ($P < 0.001$), the first null hypothesis was rejected.

The microhardness test has been used in many studies since it is an indicator of the degree of polymerization.[32] The factors significantly affecting the microhardness values of restorative materials include the filler volume fraction, composition, resin type, and polymerization degree. 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 in agreement with a study on resin composites' microhardness.[33] This can be attributed to the high resin content of this layer due to oxygen inhibition, which occurs under the celluloid strip resulting in poor mechanical properties of this layer.[34]

It was observed that all tested materials presented higher microhardness 24 h after light curing, similar to another previous study by Yazici *et al*.[9] and Yap *et al*.[29] Suitable explanations for the increased microhardness after 24 h can be because irradiation of the materials produces photoexcitation of camphorquinone molecules, resulting in the polymerization reaction. However, a significant number of free radicals remain in the bulk of the restoration after irradiation ceases, allowing the formation of polymer chains for up to 24 h, which increases the microhardness.[35]

Venturini *et al*.[15] reported that immediate polishing did not produce a negative influence on the surface roughness, hardness, and microleakage of a microfilled (Filtek A110) and a hybrid (Filtek Z250) resin composite compared to delayed polishing.

In the present study, the *posthoc* pair-wise comparison revealed that the differences in microhardness between the different polishing systems are not statistically significant as was found in a study by Canto *et al*.[36] Finishing and polishing processes remove the upper layer and reveal a surface that is farther away from the light source. There is a gradual decrease of microhardness with the increase of depth and this drop was more accentuated for depths beyond 2 mm[37] due to a decrease of irradiance of more than 75%.[38] As the depth of the samples is limited to 2 mm, the differences are not accentuated.

The differences were statistically significant among different polishing systems and the control group (for both the timings) using the one-way ANOVA test ($P < 0.001$). As two out of the three polishing systems have shown significant differences, hence, the second null hypothesis was partially rejected.

Limitations of this study can be

1. All the tests were performed on a single type of composite resin, hence the effect of varied filler sizes on surface roughness and microhardness could not be established
2. The samples were polished under dry conditions. Hence, a comparative analysis between the effect of dry and wet polishing could not be made
3. The disc-shaped polishers have limitations due to their geometry. When using the discs, it is often difficult to efficiently finish and anatomically polish contoured surfaces, especially in the posterior regions of the mouth.

CONCLUSION

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

- Although samples cured under Mylar strip have resulted in the smoothest surfaces, they have shown the least microhardness. Furthermore, the recreation of the complex tooth morphology will necessitate finishing and polishing procedures to be performed even after the curing is done under the Mylar strips
- For restorations performed using a microhybrid composite resin in esthetic areas where surface smoothness and esthetics are more of a concern than the masticatory force, immediate finishing and polishing should be done as it gives better results in terms of surface roughness and reduces the number of sessions required for the completion of the procedure as well as provides patient comfort
- Shofu Super-snap X-Treme has resulted in the smoothest surface and polishing systems containing aluminum oxide have shown better surface smoothness when used for polishing the microhybrid composite resin used in this study
- For restorations performed using a microhybrid composite resin in posterior teeth, which are subjected to more masticatory load, delayed finishing and polishing should be done as it has resulted in higher microhardness values. The type of polishing system used does not affect the microhardness of the microhybrid composite resin, however, polishing systems containing diamond abrasives should be avoided since they have resulted in surface roughness above the threshold levels.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Türkün LS, Türkün M. The effect of one-step polishing system on the surface roughness of three esthetic resin composite materials. Oper

Dent 2004;29:203-11.
2. Abzal MS, Rathakrishnan M, Prakash V, Vivekanandhan P, Subbiya A, Sukumaran VG. Evaluation of surface roughness of three different composite resins with three different polishing systems. J Conserv Dent 2016;19:171-4.
3. Mangat P, Masarat F, Rathore GS. Quantitative and qualitative surface analysis of three resin composites after polishing – An *in vitro* study. J Conserv Dent 2022;25:448-51.
4. Daud A, Gray G, Lynch CD, Wilson NH, Blum IR. A randomised controlled study on the use of finishing and polishing systems on different resin composites using 3D contact optical profilometry and scanning electron microscopy. J Dent 2018;71:25-30.
5. O'Brien WJ. Physical Properties in Dental Materials and their Selection. 4th ed. Illinois: Quintessence Publishing Co.; 2008. p. 18.
6. Ferracane JL, Mitchem JC, Condon JR, Todd R. Wear and marginal breakdown of composites with various degrees of cure. J Dent Res 1997;76:1508-16.
7. Marković D, Ćetenović B, Vuković A, Jokanović V, Marković T. Nanobiomaterials in Dentistry. New Jersey: William Andrew Publishing; 2016. p. 269-307.
8. Madhyastha PS, Hegde S, Srikant N, Kotian R, Iyer SS. Effect of finishing/polishing techniques and time on surface roughness of esthetic restorative materials. Dent Res J (Isfahan) 2017;14:326-30.
9. Yazici AR, Tuncer D, Antonson S, Onen A, Kilinc E. Effects of delayed finishing/polishing on surface roughness, hardness and gloss of tooth-coloured restorative materials. Eur J Dent 2010;4:50-6.
10. Nasoohi N, Hoorizad M, Tabatabaei SF. Effects of wet and dry finishing and polishing on surface roughness and microhardness of composite resins. J Dent (Tehran) 2017;14:69-75.
11. Thomé T, Steagall W Jr., Tachibana A, Braga SR, Turbino ML. Influence of the distance of the curing light source and composite shade on hardness of two composites. J Appl Oral Sci 2007;15:486-91.
12. 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.
13. Bashetty K, Joshi S. The effect of one-step and multi-step polishing systems on surface texture of two different resin composites. J Conserv Dent 2010;13:34-8.
14. Setcos JC, Tarim B, Suzuki S. Surface finish produced on resin composites by new polishing systems. Quintessence Int 1999;30:169-73.
15. Venturini D, Cenci MS, Demarco FF, Camacho GB, Powers JM. Effect of polishing techniques and time on surface roughness, hardness and microleakage of resin composite restorations. Oper Dent 2006;31:11-7.
16. Nagem Filho H, D'Azevedo MT, Nagem HD, Marsola FP. Surface roughness of composite resins after finishing and polishing. Braz Dent J 2003;14:37-41.
17. Albers HF. Tooth Colored Restoratives. 9th ed. Santa Rosa: CA; 2002. p. 18-9.
18. Chan KH, Mai Y, Kim H, Tong KC, Ng D, Hsiao JC. Review: Resin composite filling. Materials (Basel) 2010;3:1228-43.
19. Erdemir U, Sancakli HS, Yildiz E. The effect of one-step and multi-step polishing systems on the surface roughness and microhardness of novel resin composites. Eur J Dent 2012;6:198-205.
20. Kaminedi RR, Penumatsa NV, Priya T, Baroudi K. The influence of finishing/polishing time and cooling system on surface roughness and microhardness of two different types of composite resin restorations. J Int Soc Prev Community Dent 2014;4:S99-104.
21. Al-Mutairi SF, Somasundaram P. Comparative evaluation of surface roughness of a novel micro-filled hybrid composite with conventional and contemporary polishing systems using 3-dimensional profilometry. Int J Med Dev Ctries 2021;5:2123-8.
22. Uppal M, Ganesh A, Balagopal S, Kaur G. Profilometric analysis of two composite resins' surface repolished after tooth brush abrasion with three polishing systems. J Conserv Dent 2013;16:309-13.
23. Shrivastava A. Introduction to Plastics Engineering. New Jersey: William Andrew Publishing; 2018. p. 1-16.
24. Asmussen E, Jorgensen KD. A microscopic investigation of the adaptation of some plastic filling materials to dental cavity walls. Acta Odontol Scand 1972;30:3-21.
25. Wilson TW, Turner DT. Characterization of polydimethacrylates and their composites by dynamic mechanical analysis. J Dent Res 1987;66:1032-5.
26. Silva JP, Coelho A, Paula A, Amaro I, Saraiva J, Ferreira MM, *et al.* The influence of irrigation during the finishing and polishing of composite resin restorations-a systematic review of *in vitro* studies. Materials (Basel) 2021;14:1675.
27. Davidson CL, Duysters PP, De Lange C, Bausch JR. Structural changes in composite surface material after dry polishing. J Oral Rehabil 1981;8:431-9.
28. Yap AU, Sau CW, Lye KW. Effects of finishing/polishing time on surface characteristics of tooth-coloured restoratives. J Oral Rehabil 1998;25:456-61.
29. Mazumdar P, Mukherjee S, Khatua M. An *in vitro* study to evaluate the influence of immediate and delayed finishing and polishing procedures with two polishing systems on the surface roughness and microhardness of composite resins. Int J Curr Adv Res 2022;11:845-9.
30. Lu H, Roeder LB, Lei L, Powers JM. Effect of surface roughness on stain resistance of dental resin composites. J Esthet Restor Dent 2005;17:102-8.
31. Watanabe T, Miyazaki M, Takamizawa T, Kurokawa H, Rikuta A, Ando S. Influence of polishing duration on surface roughness of resin composites. J Oral Sci 2005;47:21-5.
32. Asmussen E. Factors affecting the quantity of remaining double bonds in restorative resin polymers. Scand J Dent Res 1982;90:490-6.
33. 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.
34. Morgan M. Finishing and polishing of direct posterior resin restorations. Pract Proced Aesthet Dent 2004;16:211-7.
35. Watts DC, McNaughton V, Grant AA. The development of surface hardness in visible light-cured posterior composites. J Dent 1986;14:169-74.
36. Canto FM, Alexandria AK, Magno MB, Silva EM, Maia LC. Topography and microhardness changes of nanofilled resin composite restorations submitted to different finishing and polishing systems and erosive challenge. Pesqui Bras Odontopediatr Clín Integr 2020;20:8-12.
37. Ciccone-Nogueira JC, Borsatto MC, de Souza-Zaron WC, Ramos RP, Palma-Dibb RG. Microhardness of composite resins at different depths varying the post-irradiation time. J Appl Oral Sci 2007;15:305-9.
38. Dionysopoulos D, Papadopoulos C, Koliniotou-Koumpia E. Effect of temperature, curing time, and filler composition on surface microhardness of composite resins. J Conserv Dent 2015;18:114-8.