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Original Research

Evaluation of the Effect of Surface Polishing, Oral Beverages and Food Colorants on Color Stability and Surface Roughness of Nanocomposite Resins

R Veena Kumari[1], Hema Nagaraj[2], Kishore Siddaraju[3], Ramya Krishna Poluri[4]

Contributors:
[1]Professor and Head, Department of Conservative Dentistry and Endodontics, MR Ambedkar Dental College and Hospital, Bengaluru, Karnataka, India; [2]Postgraduate Student, Department of Department of Conservative Dentistry & Endodontics, MR Ambedkar Dental College & Hospital, Bengaluru, Karnataka, India.
Correspondence:
Dr. Kumari RV. Department of Conservative Dentistry and Endodontics, MR Ambedkar Dental College and Hospital, 1/36, Cline road, Cooke Town, Bengaluru - 560 005, Karnataka, India.
Phone: +91-9845326564. Email: veenadentist@gmail.com
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Abstract:
Background: It is beyond doubt that finishing and polishing of a composite restoration enhance its esthetics and, is also essential for the health of the periodontium. A variety of instruments are commonly used for finishing and polishing tooth-colored restorative materials Thus, it is important to understand which type of surface finishing treatments would significantly affect the staining and surface irregularities of the composite resin restoration. Still one of the properties of the composite resins that have to pass the test of time is its color stability. In modern day dentistry, a large emphasis is laid over esthetics. Hence, it is important to understand the various agents capable of adversely affecting the esthetics of a restoration due to its staining capacity. Thus, the aim of this *in vitro* study was to evaluate the effect of surface polishing, oral beverages and food colorants on the color stability and surface roughness of nanocomposite resins.
Materials and Methods: 90 Disks of nanocomposites resin (Filtek Z350 XT) measuring 8 mm in diameter and 2 mm in thickness were fabricated using a custom made silicon mold. Pre-polishing surface roughness (Ra1) of all the 90 samples were measured using a Surface Profilometer. The nano-composite disks were then randomly divided into 3 groups with 30 samples in each group. Group I: Control group: The samples were not subjected to any polishing procedures. Group II: Sof-Lex group: Samples subjected to polishing using different grits of Sof-Lex disks. Group III: Diamond polishing paste group: Samples were subjected with a polishing paste consisting of diamond particles. Following polishing procedures, the surface roughness of all samples were measured again to obtain change in surface roughness due to polishing procedures (Ra2), pre immersion spectrophotometric value (ΔE1) was also recorded for baseline color of the samples. The samples were then divided into subgroups (A, B, C, D, E), by including every first sample in Subgroup A, second in Subgroup B, third in Subgroup C, fourth in Subgroup D, and fifth in Subgroup E. Each was immersed in the respective test solution for 10 min, twice a day for 30 days.
Group A - Tea, Group B - Coffee, Group C - Cola, Group D - Turmeric, Group E - Control (artificial saliva). Post immersion profilometric value was recorded to evaluate roughness bought about by the solutions (Ra3) and spectrophotometric value was recorded to evaluate the color change in samples (ΔE2). Results were statistically analyzed using ANOVA.
Results: Higher mean roughness (Ra2-Ra1) value was recorded in Sof-Lex, followed by Diamond polishing paste and Control group. Comparison of surface roughness caused due to beverages and food colorant solution showed subgroup C (Coca Cola) increased surface roughness in all groups (Group I, II, III). Subgroup D (Turmeric) had the highest discoloration potential (P < 0001) in all groups, followed by coffee, tea, coca-cola and artificial saliva. Sof-Lex polishing System showed most color stability.
Conclusion: Polishing procedures significantly roughen the surface of the restoration compared to the unpolished Mylar controls. One-step polishing system (diamond polishing paste) produces a smoother surface compared to a multi-step system (Sof-Lex polishing disks). Turmeric solution caused maximum staining of the samples, to a visually perceptible level.

Key Words: Nanocomposite, reflective spectrophotometer, surface profilometer

Introduction

The esthetic quality of a restoration may be as important to the mental health of the patient as the biological and technical qualities of the restoration are to his physical or dental health."

The search for the ideal esthetic material for restoring teeth has resulted in significant improvements in esthetic materials and techniques for using them. Composites and the acid etch techniques represent two major advances in restorative dentistry.[1]

Conventional dental composites with average particle sizes that far exceeded 1 μm, and typically had fillers close to or exceeding the diameter of a human hair (~50 μm), these "macrofill" materials were very strong, but difficult to polish and impossible to retain surface smoothness. In order to address the important issue of long-term esthetics, which was lacking in the macrofilled composites, manufacturers began to formulate "microfill" composites, The most recent innovation has been the development of the "nanofill" composites, containing only nanoscale particles.

These newer composite systems combine the properties of the earlier hybrid composites with the microfilled composites. Significant improvement in surface smoothness/polish retention has been reported for nanofills compared with conventional microfills. The rationale for the broader particle-size range of hybrids includes manufacturer statements of superior esthetics, surface and polishability. While comparisons with older materials may prove the hypothesis, comparisons with nanofills tend to show that their esthetics are at least non-inferior to those of nanohybrids.

Thus, these systems with the advantage of more strength, better translucency, and a smoother surface finish provide an ideal material for the anterior restorative purpose. Hence are included in this study.

Finishing and polishing devices, materials, and procedures are intended to produce intentional, selective, and controlled wear of dental restorative material surfaces.[2]

A variety of instruments are commonly used for finishing and polishing tooth-colored restorative materials including; diamond and carbide finishing burs, abrasive impregnated rigid points, impregnated rubber cups and points, aluminum oxide coated abrasive disks, abrasive strips, and polishing pastes. Each of these instruments removes the oxygen inhibited layer of the resin, but also leaves behind a varying degree of roughness. Thus, it is important to understand, which type of surface finishing treatments would significantly affect the staining and surface irregularities of the composite resin restoration.

Polish retention and the maintenance of surface quality of the restoration can be related to the filler particle size, with roughness and gloss tending to increase with particle size, nanofills and microfills, showed a reduction in gloss during tooth brushing experiments, while microhybrid composites typically show an increase in gloss after the initial stages of brushing, followed by maintenance of a steady state or slight reduction.

Still one of the properties of the composite resins that have to pass the test of time is its color stability. In modern day dentistry, a large emphasis is laid over esthetics. Today, prostheses and restorations are made with precision so as to match accurately the surrounding oral structures. As color is one of the most desirable properties of an esthetic restorative material, maintenance of the matched color for the entire length of its service life may determine the success or failure of the material. Different factors can be responsible for affecting the color stability of dental materials. Discoloration of materials may be caused by intrinsic or extrinsic factors. Intrinsic factors involve chemical changes of the material such as the oxidation of amine accelerators. These tertiary amines contribute to discoloration by a change in hue from whitish to yellow appearance. Extrinsic factors of discoloration include staining by adhesion or penetration of colorants from exogenous sources such as coffee, tea, and nicotine. Moreover, one or more of these factors may be responsible for visibly detectable or esthetically unacceptable color changes of dental materials. Thus, it is desirable that the restorative material be resistant to changes in its intrinsic color.

Humans consume food that has a high quantity of food colorants. Indian food is particularly known to have a very high quantity of ingredients, which have a high staining capacity.

Oral beverages like tea coffee and cola are thought to be the major contributors to staining of dental composites. The degree of staining, however, may vary depending on the type of composite used and its filler content, the finishing and polishing modalities, and the type of the extrinsic colorant staining it. Staining is a precursor to the bodily deterioration of the composite restoration. The severity of the discoloration can be reduced, the longevity of the restoration increased, and esthetics maintained if a restoration is fabricated with an appropriate resin. It is also essential to use a finishing and polishing system that renders the surface smooth enough to prevent adsorption of stains. Furthermore, it is crucial to avoid the consumption of food and beverages, which could probably alter the surface texture and color of the restoration.[3]

Materials and Methods

The present *in vitro* study was conducted in the Department of Conservative Dentistry and Endodontics, MR Ambedkar Dental College and Hospital, Bangalore.

Preparation of composite disks

- A total of 90 disks of composite was fabricated. The nanofilled resin was compacted and cured in increments using gold-coated plastic filling instruments in the custom made silicon mold placed on a glass slab.
- A Mylar matrix strip was sandwiched between the upper surface of the composite resin and a micro glass slide.
- Following condensation of the resin, curing of each increment of 1 mm was carried out for 40 s using a LED curing light before compaction of the next increment.
- The disks after fabrication were placed in the artificial saliva and stored at 100% relative humidity at 37°C for 24 h in an incubator for rehydration.

Measurement of pre-polishing surface roughness (Ra1)

- After 24 h the surface roughness of each sample was recorded using a Surface Profilometer.
- Surface roughness was recorded by placing the sample on the fixed table of the Profilometer and focus adjustment was done (×2.5) until interference fringe lines were visible in the monitor. The area to be scanned profilometrically was 1 mm × 0.9 mm.
- Scanning was then done to obtain the Ra value of the sample.
- The obtained value was recorded as the pre-polishing surface roughness – Ra1

- The 90 samples were then segregated randomly to constitute the three test groups – Group I, Group II and Group III

Finishing and polishing of the composite resin

- The samples were placed in a custom made putty mold for stability during the polishing procedures.
- Each specimen was polished one at a time.
- For Group II (Sof-Lex)
  Finishing and polishing of specimens belonging to this group were done using the Sof-Lex finishing and polishing disks.
  Specimens were dried and stabilized in a mold fabricated with putty elastomeric impression material prior to the polishing procedure. Polishing was carried out using a slow speed handpiece with the different grits of the disks starting from coarse, medium, and fine to superfine.
  Light to no pressure was applied during the procedure, and the disks were directed in one direction from left to right, back and forth movement was avoided.
  The coarse and medium grit disks were used in the above-mentioned method for ten strokes before proceeding to the next grit, and the fine and superfine grit disks were used for 20 strokes. Disks were discarded after a single use.
- Group III (diamond polishing paste)
  Finishing and polishing of specimens belonging to this group were carried out using a diamond polishing paste with a particle size of 0.5 μ.
  Specimens were dried and stabilized in the putty mold prior to the polishing procedure. Polishing was carried out using a slow speed handpiece and a rubber cup. The polishing paste was applied onto the surface of the sample and polished with the rubber cup for 30 s, replenishing the polishing paste whenever necessary. Following which the paste was rinsed.
  After the polishing procedure the samples of Group I and II were stored in the artificial saliva, till the time of testing.

Measurement of the post polishing surface roughness (Ra2) and pre emersion spectrophotometric value (ΔE1)

- Following polishing, the surface roughness for all samples was recorded using the Surface Profilometer.
- The color of all samples were recorded using a reflective spectrophotometer with CIELab technology to obtain the pre emersion spectrophotometric value (ΔE1), which will serve as a reference to measure color change post immersion in the beverages and food colorant.

Preparation of solutions

a. Tea
   - 15 g of tea powder (Taj Mahal) was added to 150 ml of boiling water and 150 ml of milk. Solution was boiled for 3 min, 3 cubes of sugar were added, the solution was stirred until sugar dissolved, filtered through a sieve and used.

b. Coffee
   - 10 g of instant coffee powder was added to 100 ml of warm water and 200 ml of warm milk, 3 cubes of sugar was added, stirred filtered through a sieve and used.

c. Turmeric
   - 1 g of turmeric powder was added to 300 ml of water, stirred and used.

Immersion of the composite disks in oral beverages and food colorants and measurement of color change

- Each Group of samples i.e. Group I (Control Group); Group II (Sof-Lex Group); Group III (Diamond polish Group) was again subdivided into 5 subgroups depending on the immersion solution.

The 5 subgroups were:

Group I, II, III Subgroup A (n = 6) – were immersed in Tea

Group I, II, III Subgroup B (n = 6) – were immersed in Coffee

Group I, II, III Subgroup C (n = 6) – were immersed in Coca Cola

Group I, II, III Subgroup D (n = 6) – were immersed in Turmeric solution

Group I, II, III Subgroup E (n = 6) – were immersed in Artificial saliva

The samples of subgroup A, B, C, and D were immersed in the test solutions for 10 min, twice a day for 30 days. After immersion, the samples were immersed and stored in artificial saliva at 37°C and 100% humidity in the incubator.

Measurement of post immersion surface roughness value (Ra3) and post immersion color change value (ΔE2)

- At the end of 30 days, post immersion in the test solutions. The samples were tested for the effect of the test solutions on the change in surface roughness and change in color of the nanocomposite resin.
- Surface roughness for all samples was recorded using the Surface Profilometer.
- The color of all samples were recorded using the reflective spectrophotometer with CIELab technology to obtain the post emersion spectrophotometric value (ΔE2)

Confirmation of profilometric results with scanning electron microscope

- Representative samples were selected from each subgroup (A, B, C, D, E) of all Groups (I, II, III) for examination with scanning electron microscope.
- Samples were coated with Au-Pd (5 μm) with a sputter coating machine (Quorum Q15OT ES).
- Samples were then examined under the scanning electron microscope at ×1000 magnification.

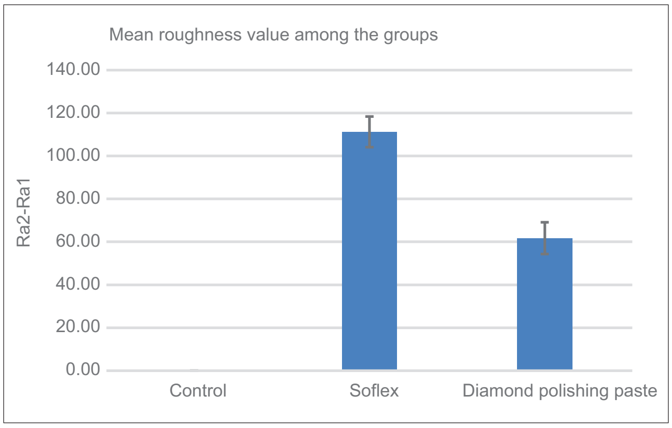
Results

Higher mean roughness (Ra2-Ra1) value was recorded in Sof-Lex, followed by diamond polishing paste and Control group (Graph 1). The difference was found to be statistically significant among the groups ($P < 0.001$). Comparison of surface roughness caused due to beverages and food colorant solution (Graph 2) showed subgroup C (Coca Cola) increased surface roughness in all groups (Group I, II, III) results were found to be statistically significant ($P < 0.001$) (Graph 3). Comparison of the change in color caused by the solutions, showed Subgroup D (turmeric) to have the highest discoloration potential ($P < 0001$) in all groups, followed by coffee, tea, coca-cola and artificial saliva (Graph 4). Comparison between polishing systems to produce most stain resistant surface showed the Sof-Lex polishing System showed most color stability.

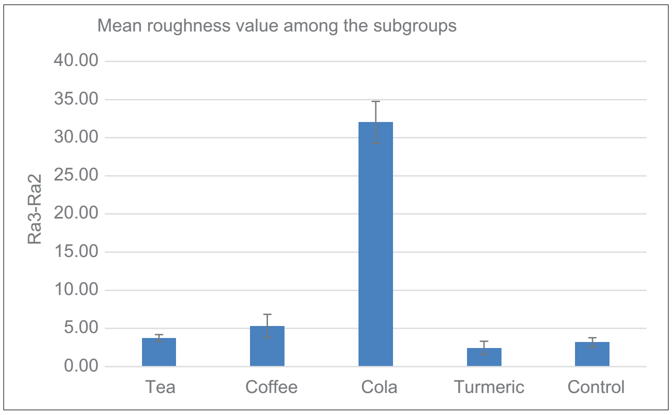
Discussion

Composite resins have been widely used since their introduction as they possess excellent esthetic properties. Initially, composite restorations were developed for esthetic restorations though these composites had several drawbacks such as, inability to bond to tooth structure, significant polymerization shrinkage. Over the time, new improved formulations were developed. A recent development includes the addition of Nano-sized fillers to the resin matrix, which gives the composite resin the handling properties, polishability of a microfilled composite in addition to the strength and wear resistance of a traditional hybrid composite resin. Included in the present study is a Nano filled resin with a filler size ranging from 4-20 nm. Other advances include composites composed of HEMA-BisGMA-TEGDMA resin with antimicrobial agent as quaternary ammonium salt monomer 2-methacryloxylethyl dodecyl methyl ammonium bromide found to be effective as a pulp capping material.[31]

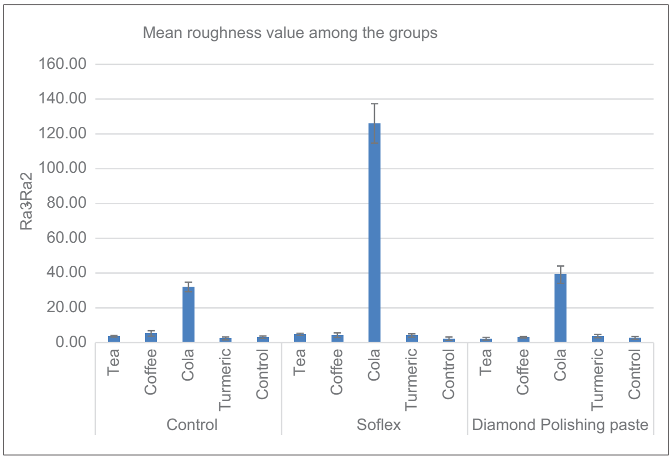
In the present study, the test samples were exposed to commonly consumed beverages such as tea, coffee, and cola and common colorant used in Indian food – turmeric, in solution form. The samples were subjected to the solutions intermittently and stored in artificial saliva continuously in an incubator at 37°C to simulate natural conditions. Measurement of color change can be assessed by visual and instrumental methods. Quantitative evaluation of color change by means of visual assessment is not possible or even useful most of



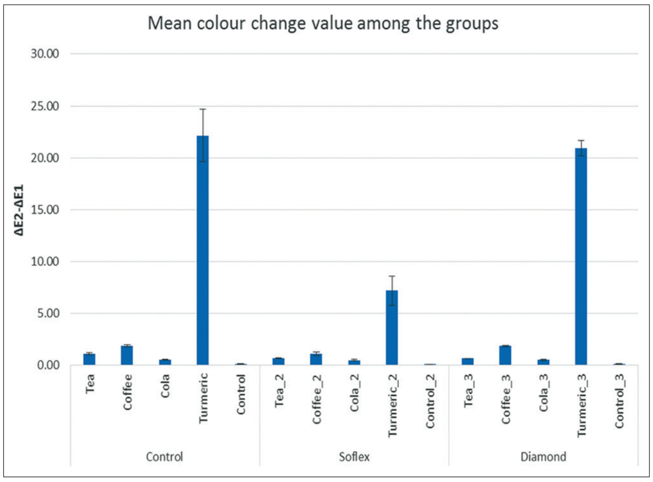
Graph 1: Comparison of mean surface roughness between Group I, II, and III.



Graph 2: Comparison of mean surface roughness in Group I among Subgroups A, B, C, D, E.



Graph 3: Comparison of mean roughness value among Subgroups of all Groups and Subgroups (I, II, III).



Graph 4: Comparision of color change due to beverages and food colorant in all groups (Group I, II, III)

the times, besides presenting low producibility.[4] Evolution in electronic optics and informatics makes the electronic techniques for color selection more adequate for daily usage. By this reason in the present study color change was tested using a spectrophotometer, DATACOLOR 650 measuring the color change using the CIELab system. According to literature, these systems are found to be more precise in comparison with measurements obtained from the calorimeter, provided they are not influenced by the environment luminosity.[5]

Color stability is also dependent upon the surface roughness of the composite restoration, as increased roughness (>0.3 μm) may lead to greater plaque retention and stain absorption than relatively smooth surfaces.[2,28]

The results obtained in the present study showed that all samples underwent some changes in color from the baseline value.

The greatest color change in all groups was caused due to the turmeric solution ($P > 0.001$). With a ΔE value >3.3 in all groups, indicating a visually perceptible, unacceptable color change. The results obtained are in accordance with the study conducted by Gupta and Gupta,[7] Malhotra *et al.*,[8] Stober *et al.*[9]

Coffee solution showed the next greatest color change, followed by Tea, Coca Cola and Control group. However, the color change due to these solutions were all within acceptable limits i.e. $\Delta E < 3.3$. Coffee solution showed the next greatest color change followed by Tea, Coca Cola and Control Group. However, the color change due to these solutions were all within acceptable limits i.e. $\Delta E < 3.3$.

Coffee has been found to be a stronger chromatogen than tea or cola. The yellow colorants of coffee are less polar than the yellow colorants of tea. Absorption and penetration of the colorants into the organic phase of the resin-based materials is probably due to the compatibility of the polymer phase with yellow colorants of coffee. Both tea and coffee contain a large amount of staining agents like Gallic acid, which could be another reason for the staining capacity of these materials. This aspect is in consensus with the study conducted by Nordbö *et al.*[10]

Hence, the results showing the discoloration potential of coffee to be greater than tea or cola is in accordance with the studies conducted by Topcu *et al.*,[11] Domingos *et al.*,[12] Fabricio *et al.*[13]

Previous studies have shown that the addition of sugar and milk powder in tea and coffee results in an increased color change, the differences that were found to be significant.[14]

With respect to color change in cola, in the present study a slight change in color was caused due to Coca-Cola, which could be attributed to the change in roughness of the samples due to the low pH (2.62) of the solution, which further aids in the adsorption of color onto its surface. Cola gains its color through the due to the presence of caramel color in its composition. These results are in agreement with Patel *et al.*[15] who stated that Coca-Cola causes a minimal change in color in the composite resins.

Polishing of restorations can be carried out with a variety of instruments, each of these instruments removes the oxygen inhibited layer of resin to improve color stability and increase surface hardness, but, also leaves behind a varying degree of roughness. Polishing systems compared in the present study include a one-step polishing system, with a three body mode of abrasion – diamond polishing paste with a multi-step polishing system, whose mode of polishing is a two-body abrasion.

It was observed in this study for the nanocomposite resin to show a decrease in the ΔE value in relation to the polishing procedure.

Removing the outermost resin layer by polishing is essential in achieving a stain resistant, more esthetically stable surface.[5,16]

The highest ΔE value was noticed in the unpolished control groups, followed by one - step polishing and finally the multi - step polishing. Results were in accordance with Schmitt *et al.*[4] It is well known that all acrylate based resins materials used in dentistry exhibit an oxygen inhibited surface layer when cured in air, the use of Mylar strips not only results in a smooth surface finish, but also eliminates the presence of an uncured layer on the surface. However, the surface beneath the strip may not have the same degree of polymerization as the bulk of the resin composite that has not been exposed to oxygen during placement of the material. It has been reported that a surface with a lower degree of polymerization can exhibit increased discolouration.[5,17] Moreover, the resin matrix tend to absorb water and are more prone to staining, more so when water is the vehicle for dye penetration.[5,17] It has also been shown that Mylar strip finishing resulted in lowest hardness due to a lower degree of polymerization on its surface. Therefore removal of this resin layer by finishing and polishing would produce a harder, more stain resistant and stable surface.[16]

Previous studies showed that the surface quality of the composite resin restoration was of prime importance to reducing external stain retention. A high gloss surface was considered less susceptible to staining than other surfaces.[18,19]

In this study, comparison of color stability between the polished groups showed samples polished with Sof-Lex disks produced a more stain resistant surface compared to Diamond polishing paste.

This observation could be attributed to the removal of the oxygen inhibited layer, more than due to the reduction of surface roughness by these polishing methods. The Sof-Lex disks with a larger grit size (coarse and medium) are more efficient in removing the surface layer. This can be justified due to the fact the Sof-Lex group showed higher mean roughness values (111.23 nm) after polishing and most resistant to color change, compared to the diamond polishing paste (61.70 nm) and, control group (0.00) with the smoothest surface showed most color change.

The surface profile of the restoration can be improved by finishing and polishing procedures, whereas, on the other hand, increased roughness of the restoration surfaces can be caused by brushing, acid reflux, and varying pH of various food and beverages we consume.

In polishing with abrasive particles, the wear mechanism is mostly abrasive wear, but other mechanisms are also possible. These include surface fatigue and development of ploughing grooves or scratches, which in some instances are accompanied by hertzian fractures.[2]

Surface roughness in the present study was measured using a profilometer. A profilometer is a device used to measure the roughness of a surface. Advantages of optical profilometers include good resolution: Vertical resolution is usually in the nm level, high speed, reliability: Cannot be damaged by surface wear or careless operators, spot size or lateral resolution, which ranges from a few micrometers down to sub-micrometre. In this study, the surface roughness of the samples caused due to polishing procedures, and beverages were measured using a non - contact surface profiler Veeco NT1100at ×2 magnification. Both two-dimensional and three-dimensional images of the samples can be obtained with this profiler. Readings obtained were analyzed on the monitor using the VISION 32 software.

In the present study, the smoothest surface was obtained in the control group ($P < 0.001$), cured under the Mylar matrix strip and not subjected to any polishing procedures. Polishing procedures was observed to increase the surface roughness of the nanocomposite resin. This is in accordance with previous studies carried out to evaluate different polishing systems for polishing a composite resin.[20-23]

Even though smooth surfaces are obtained with the Mylar matrix, removing the outermost resin layer by polishing is essential in achieving a stain resistant, more esthetically stable surface.[5,16]

Also, it is more difficult to contour the restoration with a Mylar matrix strip on the curved surfaces of the tooth.

An increase in surface roughness was observed in both polished groups i.e. the Sof-Lex group (111.23 nm) and the diamond polish group (61.70 nm) compared to the control group (00 nm).

Among the polished groups, the smoothest surfaces were seen in the diamond polishing paste group compared to the samples polished with the Sof-Lex polishing disks ($P < 0.001$). This could be attributed to the hardness of the diamond particles, which enables it to remove both phases of the composite resin i.e. the resin matrix and filler particles homogeneously. Also, the ability of the polishing paste to freely move over the surface allows for even wear of the restoration surface.

The above results are in accordance with Lainovića *et al*.[24]

The rougher surface seen on the Sof-Lex polished groups could be attributed to the larger particle size of the aluminum oxide abrasive used, ranging from 92 to 98 μm for the coarse grit disk, to 2-5 μm for the extra fine grit disk. Even the smallest particle size in the Sof-Lex disks i.e. 2-5 μm is greater than the abrasive particle size in the diamond polishing paste i.e. 0.5 μm. The lesser flexibility of the disks also makes it difficult to polish the surface evenly. A greater amount of wear/removal of the surface layer was also observed in this group.

Two hot beverages Tea and Coffee, one cold beverage Coca-Cola, and a solution of food colorant (Turmeric) were included in the present study to study their effect on surface roughness and color stability of the restoration.

As most beverages including coffee, tea are colloidal suspensions that will precipitate sediments after standing in stagnation, the staining outcome by prolonged immersion may have no resemblance to clinical realities.[12] Hence in the present study, the samples were exposed to the test solutions intermittently[25-27] to simulate oral conditions, and immersion was carried out twice a day to simulate medium frequency consumption conditions.

An increase in surface roughness following immersion in solutions were in the following order: Coca-Cola > Coffee > Tea > Turmeric > Control. Samples immersed in Coca Cola showed increased roughness in all groups ($P < 0.001$). This could be attributed to the susceptibility of the composite resin to chemical erosion of the resin matrix due to the low pH of the cola, this results in the hydrolytic breakdown of the filler particles and chemical degradation of the silane agent, which can further be responsible for their discoloration.

Increase in roughness was also seen coffee and tea, even though to a small extent this change in surface roughness could be due to expansion of the polymer phase.[28] da Silva *et al.* detected significant degradation of the resin matrix with immersion in coffee.[29] They concluded that the consumption of coffee did not affect the microhardness of the composite resin, but its surface roughness was altered in the analyzed period. Similarly, Dos Santos *et al.* detected significant degradation of resin matrix upon immersion in coffee at high temperature.[30]

Therefore the results of the present *in vitro* study provide an insight for the clinicians about the importance of polishing procedures, and their effect on the restoration. Also, it gives an insight about the effects of the commonly consumed food and beverages on the color stability and surface profile of the restoration. A knowledge of these factors allows the clinician to select the appropriate polishing system and also inform the patient to limit the consumption of food and beverages detrimental to the restoration.

Conclusion

Polishing procedures significantly roughen the surface of the restoration compared to the unpolished Mylar controls. One step polishing system (diamond polishing paste) produces a smoother surface compared to a multi-step system (Sof-Lex polishing disks). Coca-Cola was seen to significantly roughen the surface of the composite resin compared to other oral beverages, whereas Turmeric solution caused maximum staining of the samples, to a visually perceptible level, followed by Coffee and Tea. Coca-Cola and artificial saliva caused minimal staining. Sof-Lex polishing system makes the restoration more resistant to discoloration, compared to the Diamond polishing paste.

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