Original Article

Comparative Evaluation of Surface Roughness and Wettability of an Alkasite with Nano Bulk-Fill and Nanofilled Resin Composite Restorative Materials: *In vitro* Study

Shrehya Shekhar[1], Baranya Shrikrishna Suprabha[1], Ramya Shenoy[2], Srikant Natarajan[3], Arathi Rao[1]

[1]Department of Pediatric and Preventive Dentistry, Manipal College of Dental Sciences, Mangalore, Manipal Academy of Higher Education, Manipal, Karnataka, India, [2]Department of Public Health Dentistry, Manipal College of Dental Sciences, Mangalore, Manipal Academy of Higher Education, Manipal, Karnataka, India, [3]Department of Oral and Maxillofacial Pathology, Manipal College of Dental Sciences, Mangalore, Manipal Academy of Higher Education, Manipal, Karnataka, India

Abstract

Context: Surface characteristics of resin-based composites (RBCs) can change with polishing and over time. **Aim:** The aim of the study was to compare the surface roughness and wettability of three different posterior RBCs after polishing and the change in these surface characteristics over time, after aqueous aging. **Settings and Design:** Experimental *in vitro* study. **Materials and Methods:** Eleven disc-shaped RBC specimens were fabricated. The RBCs used were, alkasite composite, bulk-fill nanocomposite, conventional nanofilled composite. All the specimens underwent polishing with Soflex Diamond Polishing System and then analyzed for roughness and wettability at baseline and after aqueous aging for 3 months with the help of an atomic force microscope and a contact angle goniometer respectively. **Statistical Analysis:** One-way ANOVA and Tamhane test were used for the multiple comparisons. **Results:** Alkasite composite showed significantly higher surface roughness ($P = 0.028$ and $P < 0.001$, respectively) and lower wettability ($P = 0.023$ and $P = 0.020$, respectively) than conventional nanofilled composite at baseline and 3 months. Surface roughness of alkasite composite was also significantly higher than bulk-fill nanocomposite ($P = 0.009$ and $P < 0.001$, respectively) at both the time points. **Conclusions:** Alkasite has higher surface roughness in comparison to conventional nanocomposite and bulk-fill nanocomposite and lower wettability than conventional nanocomposite after polishing and aqueous aging over a 3-month period. In terms of surface characteristics, alkasite composite may be advantageous in preventing initial plaque adhesion to the material surface, but the lower surface roughness of nano-filled composites may be more advantageous in terms of plaque retention prevention.

Keywords: *Aging, atomic force microscopy, composite resin, polishing, wettability*

Introduction

Resin based composites (RBCs) have an established application in restoration of primary and permanent teeth. Their ability to mimic tooth structure has given them a clear edge for use and acceptance by both patients and dental professionals.[1] The type of filler affects their physical properties such as the strength, polymerization shrinkage, surface characteristics, and polishability.[2] Formulation of filler particles has evolved from macro, micro, down to nanoparticles.[3] Nanocomposites with filler particle size <100 nm, have low shrinkage, better polishability, and greater wear-resistance.[4]

Bulk-fill resin composites that are currently extensively used allow the number of increments required to fill a cavity to be reduced. Unlike the standard 2-mm increments recommended for traditional RBCs, increments of 4 mm–5 mm are used for the bulk-fill RBCs. This simplifies the restorative procedure, reduces clinical time, and improves patient compliance in cases of deep, wide cavities.[5] However, the advantage of the faster restorative procedure with light-cured bulk-fill RBCs is offset by the uncertainty of sufficient in-depth curing. This has led to the development of dual-curing RBCs that are also suitable for bulk-filling procedure.[6]

Recently, a dual-cured resin-based bulk-fill composite with alkaline fillers, referred to as alkasites was introduced as a tooth-colored, basic filling material for bulk placement in retentive preparations. They have bioactive properties and release acid-neutralizing ions to prevent tooth demineralization.[6,7]

How to cite this article: Shekhar S, Suprabha BS, Shenoy R, Natarajan S, Rao A. Comparative evaluation of surface roughness and wettability of an alkasite with nano bulk-fill and nanofilled resin composite restorative materials: *In vitro* study. Contemp Clin Dent 2022;13:337-43.

Submitted : 01-Feb-2021
Revised : 13-May-2021
Accepted : 09-Jul-2021
Published : 03-Nov-2022

Address for correspondence:
Dr. Baranya Shrikrishna Suprabha, Department of Pediatric and Preventive Dentistry, Manipal College of Dental Sciences, Light House Hill Road, Mangalore - 575 001, Karnataka, India.
E-mail: suprabha.bhat@manipal.edu

Access this article online

Website: www.contempclindent.org

DOI: 10.4103/ccd.ccd_95_21

Quick Response Code:

The success of RBC restorations is limited by their vulnerability to secondary caries. Susceptibility of RBCs to plaque biofilm colonization, causative to secondary caries is dependent on the surface characteristics of the RBC such as surface roughness and wettability.[8] Surface roughness has a significant effect on discoloration of restorations and gingival irritation.[2,9] Finishing and polishing techniques are employed to decrease the surface roughness of RBC restorations. The type of inorganic filler, the size of the particles, and the magnitude of the filler loading influence the polishability of RBCs.[10]

Surface wettability of the material is determined by contact angle measurements (angle formed by the solid sample surface and the tangent at the surface of the liquid drop) and gives an insight to the hydrophobicity of the material. As the angle increases, the wettability decreases and is an indicator of free surface energy, which plays an important role in bacterial adhesion.[11,12] Earlier studies have shown that the wettability of the RBC varies with surface roughness and the composition of the RBCs.[8,13]

In addition, surface characteristics of RBCs can change over time. Aqueous aging studies have shown a change in surface characteristics after immersion in water.[3,14] No extensive studies have been done comparing the surface characteristics of commonly used RBCs such as nanocomposites and bulk-fill composites with the relatively newer alkasite material.

Hence, the purpose of this *in vitro* study was to estimate and compare the surface roughness and wettability of nanofilled, alkasite and bulk-fill RBCs used for posterior teeth restorations, after polishing. In addition, the changes in surface roughness and wettability over time, after aqueous aging were to be measured.

The null hypothesis was that there is no significant difference in the surface roughness and wettability between the resin composites after polishing and aqueous aging.

Materials and Methods

Sample preparation

The sample size was calculated by using a resource equation where E should be between 10 and 20 (E = (n × G)−G/G), where n = total number of specimens; G = total number of groups.[15] Assuming n = 11 and G = 3 and a 10% loss of sample, final sample size will be 11. Hence, the sample size was approximated to 11, since it is the closest number between 10 and 20.

The study was approved by the Institutional Ethics Committee, prior to the commencement of the study. Eleven -disc-shaped specimens of each RBC were fabricated:

Group 1

Alkasite composite (Cention N, Ivoclar Vivadent Inc, NY, USA).

Group 2

Bulk-fill nanofilled composite (3M Filtek™ One Bulk-fill Restorative, 3M ESPE, St Paul, MN, USA).

Group 3

Conventional nanofilled composite (Filtek Z350 XT, 3M ESPE, St Paul, MN, USA).

Details regarding the composition of the materials studied are given in Table 1. Each type of resin composite material was condensed in a single increment into a customized metal mold of 8 mm × 2 mm dimension, using a smooth surface round-ended condenser. Excess material was removed with a plastic filling instrument. To obtain a flat surface without any defects and entrapped air, specimens was covered with a Mylar strip (SS White Co, Philadelphia, Pennsylvania, USA) and a uniform pressure was applied with a microscope glass slide.

All specimens were polymerized through the glass slide using a light-emitting diode curing light (BLUEDENT, BG LIGHT LTD, Plovdiv, Bulgaria) at an intensity of 1200 mW/cm^2, as recorded by radiometer (Demetron 100, Demetron Research Corp., Danbury, CT, USA) for 20 s in the continuous mode. After retrieving the sample from the mold, the surfaces were examined for voids and checked for the dimensions with the help of a calliper. The samples with voids were discarded. All the specimens underwent finishing using a tungsten carbide 12-fluted bur (SS White, Lakewood, New Jersey, USA) in a single-direction to remove flash. Polishing was done with Soflex Diamond Polishing System (3M ESPE, St Paul, MN, USA). The specimens were first treated with prepolishing spiral followed by the diamond polishing spiral for 30 s, each with moderate pressure in a single-direction, using a micromotor handpiece (NSK Inc, Tokyo, Japan) at a speed of 10,000–20,000 rpm. The specimens were then rinsed with water for 10 s and air-dried for 5 s. The polishing spirals were replaced after each use and tungsten carbide bur were replaced after every three specimens. The specimens were then stored in distilled water for 24 h at 37°C in a plastic container with a sealed lid in an incubator (SANYO Incubator MIR-253, SANYO Electric Co., Ltd., Sakata, Oizumi-Machi, Ora-Gun, Gunma, Japan). The same operator performed all the procedures, to standardize the finishing and polishing procedures.

Surface roughness measurement

After specimen preparation, a baseline measurement of the surface roughness was done after 24-h by observing under an atomic force microscope (AFM) (Innova™, Bruker Corporation, Coventry, UK) with a probe with a length of 125 μm, width of 40 μm and tip thickness of 3.4 μm, under tapping mode. Specimens were air-dried prior to observation under AFM and were placed on a sample-mounting disk made of stainless steel (15 mm diameter). Specimen scanning was done

Table 1: Details of the tested materials: Alkasite composite, bulk-fill nanocomposite, conventional nanocomposite

Material group	Type	Matrix	Filler type and filler size	Filler loading (volume percentage/weight percentage)	Manufacturer, shade and lot number
Group 1	Alkasite composite	UDMA, DCP, an aromatic aliphatic-UDMA and PEG-400 DMA	Barium aluminum silicate glass filler, ytterbium trifluoride, isofiller (tetric N-ceram technology), calcium barium aluminum fluorosilicate glass filler, calcium fluorosilicate (alkaline) glass filler 0.1-35 µm	57.6/78.4	Ivoclar Vivadent Inc, NY, USA A2 Lot number Y25391
Group 2	Bulk-fill nanofilled composite	AUDMA, AFM	Nonagglomerated silica filler ~20 nm Nonagglomerated zirconia filler ~4-11 nm Agglomerated ytterbium trifluoride ~100 nm	58.4/76.5	3M Filtek™ one bulk-fill restorative, St Paul, MN, USA A2 Lot number N719050
Group 3	Nanofilled composite	Bis-GMA, UDMA, TEGDMA, and bis-EMA resins	Nonagglomerated silica filler (20 nm) Nonagglomerated/zirconia filler (4-11 nm) Aggregated zirconia/silica Cluster filler (comprised of 20 nm silica and 4-11 nm zirconia particles)	63.3/78.5	3M™ ESPE, Filtek™ Z350 XT, St Paul, MN, USA A2 Lot number NA21364

DCP: Dimethanol dimethacrylate; PEG-400: Polyethylene glycol 400; UDMA: Urethane dimethacrylate; TEGDMA: Triethylene glycol dimethacrylate; BisGMA: Diglycidildimethacrylate; AUDMA: Aromatic urethane dimethacrylate; AFM: Addition-fragmentation monomer; BisEMA: Ethoxylated version

at three points (one point each at the center of the specimen, at specimen's perimeter and at half distance between specimen's center and perimeter), and the mean average value was obtained.[2] Three images (751 × 751 pixels) were collected for each specimen with a scan size of 10 µm × 10 µm and a scan rate of 1.00 Hz. Measured topography data were analyzed using Nanoscope Analysis Version 1.5 software. (Bruker Corporation, Coventry, West Midlands, UK)

Surface roughness was expressed as average Ra value (arithmetical average value of all absolute distances of the roughness profile) in nanometers. These measurements were repeated after 90 days with the same specimens. During this time interval, all the specimens were stored in distilled water, away from the direct sunlight, in a plastic container with a sealed lid and placed in an incubator at a temperature of 37°C, for aqueous aging. The distilled water in the plastic container was changed every day. All AFM scans were performed by the same, trained operator, who was blinded to the type of the composite resin analyzed.

Contact angle measurement

To assess wettability, contact angle measurements were obtained using a contact angle goniometer (Holmarc opto-mechatronics Pvt. Ltd, Kochi, Kerala, India) with an attached camera to capture the image at a resolution of 2592 × 1944 pixels. The measurement was done by sessile-drop-method in which deionised water was dropped perpendicular to the substrate surface at the room temperature to the center of the sample, placed in a perfectly horizontal position. The volume for each drop of water was standardized to 2 µL using 50 µL syringe dispenser. The time interval between each recording was standardized to 5-s and two readings were taken (left and right) each time at four regions (upper-right, upper-left, lower-right, lower-left) of the specimen. The image obtained at each time point was analyzed with the inbuilt image analyser software of the goniometer, to obtain the contact angle (the angle formed between the liquid – Solid interfaces). Ten readings at 5-s interval were taken in each of the four regions per sample and the average mean angle was calculated.[13] These measurements were repeated after 90 days with the same specimens that were stored in the incubator at 37°C in distilled water for aqueous aging and thus a total of 1760 measurements per group were taken in the span of 3 months. The procedure for measuring the contact angle was the same for all groups and was performed by the same, trained operator who was blinded to the type of composite used.

Statistical analysis

Data were analyzed using IBM SPSS Statistics for Windows, Version 20 (IBM Corp., Armonk, NY, USA). Mean surface roughness (Ra) and contact angle values for each group were calculated. Intergroup and intragroup comparison at two-time interval was done using the one-way ANOVA and paired *t*-test, respectively. Multiple comparisons were done using Tamhane test. To analyze the effect of time and type of composite on the Ra and contact angle values, a multivariate regression analysis was performed using the general linear model. $P < 0.05$ was considered statistically significant.

Results

Quantitative analysis of the Ra values using one-way ANOVA showed a significant difference between the

groups [Table 2] with the highest value for Group 1 and lowest for Group 2. For further intergroup comparison, *post hoc* test (Tamhane) was applied and it was found that Group 1 values were significantly higher than Group 2 at both baseline and 3 months (P = u 0.009 and $P < 0.001$, respectively). Group 1 also showed a significantly higher value than Group 3 at both baseline and 3 months ($P = 0.028$ and $P < 0.001$, respectively). There was no significant difference between Group 2 and Group 3 at both time points ($P = 0.867$ and $P = 0.705$, respectively). Thus, the alkasite composite had higher surface roughness than both conventional nanofilled and bulk-fill nanocomposite.

The surfaces showed slight increase in Ra over a 3-month period of aqueous aging for both Groups 1 and 2 but a slight decrease for Group 3 [Table 2]. However, the differences were not significant ($P = 0.431$, 0.949, and 0.938, respectively, for Groups 1, 2, and 3), as shown by paired *t*-test.

Qualitative analysis of the AFM images showed that the polishing procedure generated lines and scratches on the material surfaces. The polishing system formed a surface with furrowed and micro ploughed topography, with valleys and peaks formed due to dislodgment of resin matrix as well as filler particles, exposing the remaining filler particles. While Group 1 (alkasite) showed multiple depression areas indicating loss of matrix as well as filler particles, Group 2 (bulk-fill nanocomposite) showed a more uniform surface with deep scratch lines and occasional blunted peaks and ridges, whereas Group 3 showed a regular pattern of peaks and valley distribution. Comparing the images at baseline and 3 months, Group 1 showed increase in irregularities with shortening and blunting of the peaks while Group 2 showed an increase in irregularity with more prominent peaks and appearance of new areas of depression, signifying loss of fillers and matrix. For Group 3, compared to the 1st month, peaks were wider and more rounded, with deeper valleys and grooves seen, compatible with marginal increase in irregularity [Figures 1 and 2].

The comparison of the mean contact angles of the three groups also revealed a significant difference between the groups at baseline and 3 months [Table 3] with highest value in Group 1 and lowest value in Group 3. Intergroup comparisons with Tamhane test revealed a significant difference in the contact angle values between Group 1 and Group 3 ($P = 0.023$ and 0.020 at baseline and 3 months, respectively). There was no significant difference between Groups 1 and 2 ($P = 0.309$ at both baseline and 3 months) and Groups 2 and 3 ($P = 0.451$ and 0.301 at baseline and 3 months, respectively). Thus, the alkasite showed significantly lower surface wettability than nanofilled composite, while it was comparable with bulk-fill nanocomposite.

Contact angle values [Table 3] showed a slight increase over the period of aqueous aging for both Groups 1 and 2, but a negligible decrease for Group 3, the differences not shown to be significant by the paired *t*-test analysis ($P = 0.126$, 0.211, and 0.519 for Groups 1, 2, and 3, respectively).

Since the values obtained varied by two categorical variables (type of composite and time), the mean values of surface roughness and wettability were entered into general linear models with *post hoc* tests. There was a significant difference in Ra values between the composites irrespective of aqueous aging for 3 months ($F = 16.94$; $P < 0.001$) with *post hoc* test revealing a significant difference between Groups 1 and 2 ($P < 0.001$) as well as Group 3 ($P < 0.001$). Significant differences were also seen in the surface wettability using general linear model ($F = 5.19$; $P = 0.012$) with a significant difference between Group 1 and 3 ($P = 0.021$), regardless of aqueous aging.

Discussion

A mean surface roughness of 0.3 μm can be easily detected by the tongue tip, causing discomfort to patients. When the value is above 0.2 μm, there is high risk of plaque accumulation, increasing the risk of secondary caries.[12,16,17] The range of mean surface roughness values obtained in this study (0.058 μm–0.098 μm) is thus clinically acceptable.

The results of our study showed that the alkasite had the highest roughness when compared to conventional nanofilled and bulk-fill nanocomposite. Previous studies

Table 2: Surface roughness measurements (Ra in nm) at baseline and 3 months

Groups	Mean±SD	
	Baseline	3 months
Group 1	64.13±0.08^{a,ab}	64.37±0.71^{a,ab}
Group 2	61.94±4.21^{b,ab}	62.37±3.81^{b,ab}
Group 3	59.25±4.87^{b}	59.21±5.02^{b}
F	4.75	5.56
P	0.016*	0.009*

*P<0.05: Significant; Same alphabets in superscript denote no statistical difference. SD: Standard deviation

Table 3: Contact angle measurements (°) at baseline and 3 months

Groups	Mean±SD	
	Baseline	3 months
Group 1	98.80±29.58^{a}	105.61±13.04^{a}
Group 2	58.06±27.26^{b}	58.36±20.41^{b}
Group 3	65.74±23.76^{b}	65.24±10.28^{b}
F	7.08	31.06
P	0.003*	<0.001*

*P<0.05: Significant; Same alphabets in superscript denote no statistical difference. SD: Standard deviation

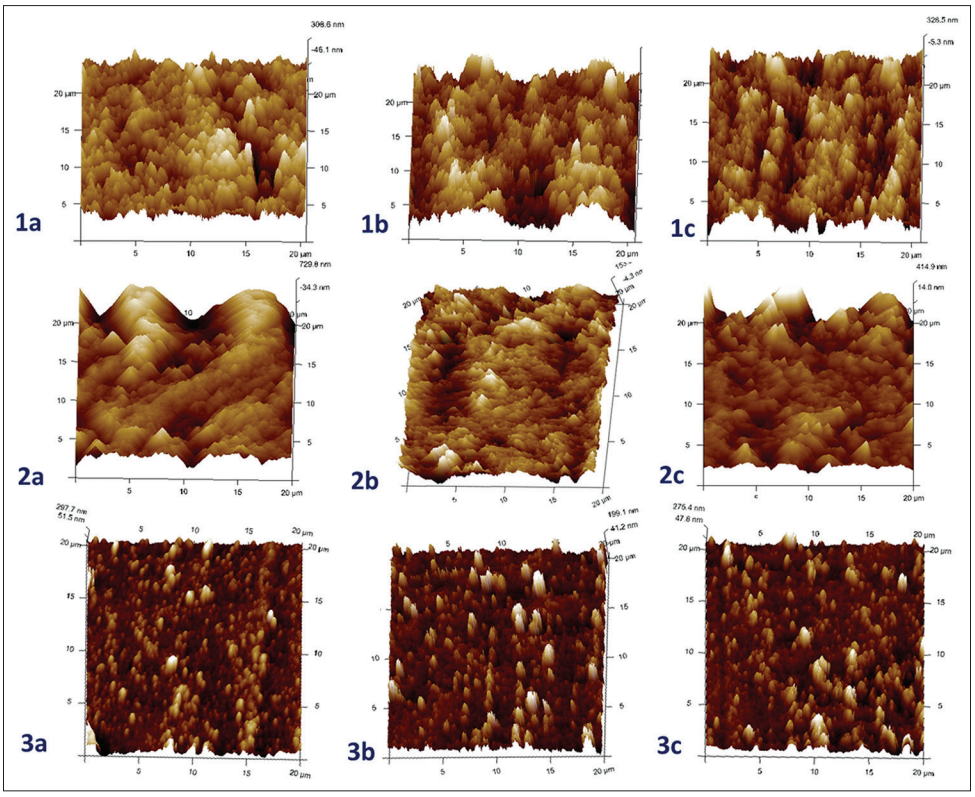

Figure 1: Atomic force microscope image of the polished surfaces of the resin-based composite specimens at baseline. 1a, 2a, 3a: center of the specimen; 1b, 2b, and 3b at half distance between specimen's center and perimeter and 1c, 2c, 3c at specimen's perimeter

comparing surface roughness of various composite materials have shown that the surface roughness of the RBCs is affected by their composition, especially the size, shape, hardness, and amount of filler particles.[2,9,18] Alkasite resin composite has higher filler particle size and least filler load of all the composites and thus showed highest surface roughness values. Qualitative analysis of the AFM images also showed higher areas of loss of resin matrix and fillers in this group when compared to the more regular surface topography for nanocomposites. The results of our study are similar to a study done by Senawongse and Pongprueksa[19] which stated that nanofilled resins show the least surface roughness due to the presence of nanoclusters and their higher filler content.

During finishing and polishing, some amount of resin matrix is lost, exposing the fillers.[20] Higher filler loading also means more filler particles are in contact with the polishing instrument, which minimizes excessive abrasion of the resin matrix. Some amount of the filler particles may also be lost during polishing, and the loss is greater when the hardness level, which is determined by filler load, is lower. Loss of larger and irregular filler particles leave larger voids, increasing the surface roughness.[21,22] Alkasite has larger dimensions of filler particle size when compared to nanofilled RBCs, with a heterogeneous range of 0.1–35 μm.

In vitro aging method uses exposure of the material to chemicals such as water or ethanol.[23] They give us an understanding of the degradation of properties of the material in the oral environment, as *in vivo* studies are more time-consuming and expensive to carry out.[24] Exposure of RBCs to water results in rapid elution of the unreacted monomers in the first 1–4 weeks, resulting in the formation of voids/pores.[25] Simultaneously, water absorbed by the resin occupies the voids/pores and the space between the polymer chains by a slow, diffusion-controlled process. This affects the mechanical properties of the resin as secondary chain interaction during polymerization is affected.[24,25] It has been shown that urethane dimethacrylate (UDMA)-based resins show more degradation in aqueous environment than bisphenol A-glycidyl methacrylate (Bis-GMA) resins.[24] This explains the increase in surface roughness values after 90 days of aqueous aging in this study, although not significant, for alkasite and bulk-fill nanocomposites, as both are UDMA based. Weakening of resin matrix due to aging results in dislodgments of the filler particles leading to roughening of the surface. RBCs with higher filler loading show decreased surface degradation during aging.[24,26]

In this study, contact angle measurement was higher for alkasite resin composite, implying less wettability and hence less susceptible to bacterial adhesion than conventional nanofilled resin composite. Ability of the resin composite to release fluoride influences the surface wettability which may be one of the factors leading to lower wettability of the alkasite.[13,27] For nanocomposites,

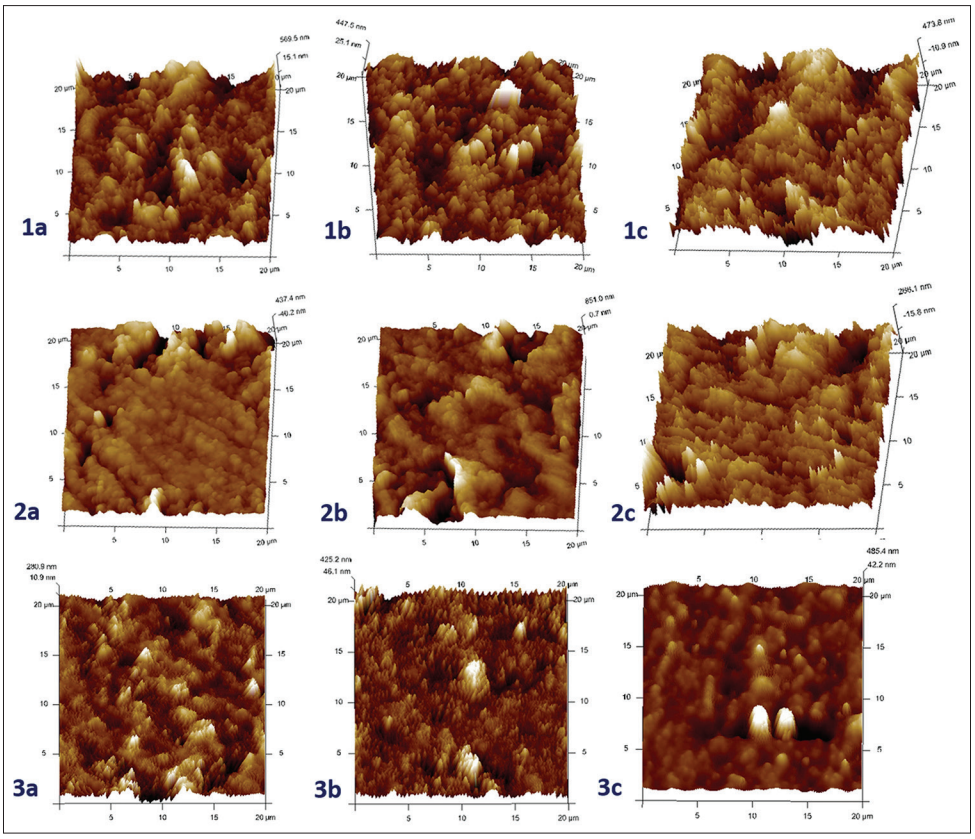

Figure 2: Atomic force microscope image of the polished surfaces of the resin-based composite specimens after 3 months. 1a, 2a, 3a: center of the specimen; 1b, 2b, 3b at half distance between specimen's center and perimeter and 1c, 2c, 3c at specimen's perimeter

lower contact angles were observed due to higher filler content.[3] This difference in wettability plays an important role in initial plaque adhesion.[3,18]

If the contact angle is 60°–86°, surface roughness has no influence on surface wettability.[28] This was the case with alkasite resin composite, which had the highest surface roughness but least wettability. However, surface roughness influences the bacterial adhesion to the material surface to a greater extent than the surface free energy and has an important role in plaque retention, as the rough surface protects bacteria against shear forces.[12,27] Thus, it may be inferred that nanofilled composites are more advantageous in terms of surface characteristics than alkasite resin composite.

AFM method allows 3D imaging at a nanometric resolution, giving a better description about the surface topography with more precise readings.[20] However, it gives only localized values of surface roughness, as compared to surface profilometry, which gives more global values.[9] Another limitation is the use of only water as the aging medium. The effect of other mediums such as artificial saliva, acids, and ethanol needs to be evaluated. It should be noted that *in vivo* conditions, the change in the surface roughness due to aqueous aging and the wettability of the material is altered by the presence of salivary pellicle, which is not considered in an *in vitro* design.[27,29] Hence, further clinical studies are needed to evaluate the surface characteristics of these composites.

Conclusions

Within the limitations of the study, it can be concluded that alkasite has higher surface roughness in comparison to conventional and bulk-fill nanocomposite and lower wettability in comparison to conventional nanocomposite after polishing with a diamond polishing system and aqueous aging over 3 months. In terms of surface characteristics of the resin composite material, which influences plaque biofilm colonization and hence secondary caries, alkasite composite may be advantageous only in preventing initial plaque adhesion to the material surface, but the lower surface roughness of nanocomposites may be more advantageous in terms of plaque retention prevention.

Acknowledgment

The authors thank and acknowledge Dr. Satish Shenoy, Head of the Department, Department of Aeronautical Automobile Engineering and Department of Innovation Center, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, for facilitating work regarding AFM and Dr. Santosh Chidangil, Head of the Department, Department of Atomic and Molecular Physics,

Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, for the expertise provided during the contact angle measurements.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Chesterman J, Jowett A, Gallacher A, Nixon P. Bulk-fill resin-based composite restorative materials: A review. Br Dent J 2017;222:337-44.
2. Lainović T, Vilotić M, Blažić L, Kakaš D, Marković D, Ivanišević A. Determination of surface roughness and topography of dental resin-based nanocomposites using AFM analysis. Bosn J Basic Med Sci 2013;13:34-43.
3. Krüger J, Maletz R, Ottl P, Warkentin M. *In vitro* aging behavior of dental composites considering the influence of filler content, storage media and incubation time. PLoS One 2018;13:e0195160.
4. Chen MH. Update on dental nanocomposites. J Dent Res 2010;89:549-60.
5. Ilie N, Bucuta S, Draenert M. Bulk-fill resin-based composites: An *in vitro* assessment of their mechanical performance. Oper Dent 2013;38:618-25.
6. Ilie N. Comparative effect of self-or dual-curing on polymerization kinetics and mechanical properties in a novel, dental-resin-based composite with alkaline filler. Materials 2018;11:108.
7. Todd JC. Scientific Documentation: Cention N. Schaan, Liechtenstein: Ivoclar-Vivadent Press; 2016. p. 1-58.
8. Nedeljkovic I, De Munck J, Ungureanu AA, Slomka V, Bartic C, Vananroye A, *et al.* Biofilm-induced changes to the composite surface. J Dent 2017;63:36-43.
9. Janus J, Fauxpoint G, Arntz Y, Pelletier H, Etienne O. Surface roughness and morphology of three nanocomposites after two different polishing treatments by a multitechnique approach. Dent Mater 2010;26:416-25.
10. Endo T, Finger WJ, Kanehira M, Utterodt A, Komatsu M. Surface texture and roughness of polished nanofill and nanohybrid resin composites. Dent Mater J 2010;29:213-23.
11. Preoteasa CT, Sultan AN, Popa L, Ionescu E, Iosif L, Ghica MV *et al.* Wettability of some dental materials. Optoelectron Adv Mater Rapid Commun 2011;5:874-8.
12. Sturz CR, Faber FJ, Scheer M, Rothamel D, Neugebauer J. Effects of various chairside surface treatment methods on dental restorative materials with respect to contact angles and surface roughness. Dent Mater J 2015;34:796-813.
13. Namen F, Galan J Jr., de Oliveira JF, Cabreira RD, Silva Filhoa FC, Souza AB, *et al.* Surface properties of dental polymers: Measurements of contact angles, roughness and fluoride release. Mater Res 2008;11:239-43.
14. Cenci MS, Venturini D, Pereira-Cenci T, Piva E, Demarco FF. The effect of polishing techniques and time on the surface characteristics and sealing ability of resin composite restorations after one-year storage. Oper Dent 2008;33:169-76.
15. Smith S. Determining Sample Size: How to Ensure You Get the Correct Sample Size. E-Book (c) Qualtrics Online Sample; 2013. Available from: https://www.qualtrics.com/blog/determining-sample-size. [Last accessed on 2019 Jan 12].
16. Jones CS, Billington RW, Pearson GJ. The *in vivo* perception of roughness of restorations. Br Dent J 2004;196:42-5.
17. Bollen CM, Lambrechts P, Quirynen M. Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: A review of the literature. Dent Mater 1997;13:258-69.
18. Can Say E, Yurdagüven H, Yaman BC, Özer F. Surface roughness and morphology of resin composites polished with two-step polishing systems. Dent Mater J 2014;33:332-42.
19. Senawongse P, Pongprueksa P. Surface roughness of nanofill and nanohybrid resin composites after polishing and brushing. J Esthet Restor Dent 2007;19:265-73.
20. 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;18:155-63.
21. Itanto BS, Usman M, Margono A. Comparison of surface roughness of nanofilled and nanohybrid composite resins after polishing with a multi-step technique. J Physics 2017;884:012091.
22. 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.
23. Rocha RS, Oliveira AC, Caneppele TM, Bresciani E. Effect of artificial aging protocols on surface gloss of resin composites. Int J Dent 2017;2017:3483171.
24. Sideridou ID, Karabela MM, Bikiaris DN. Aging studies of light cured dimethacrylate-based dental resins and a resin composite in water or ethanol/water. Dent Mater 2007;23:1142-9.
25. Rocha AC, Lima CS, Santos MD, Montes MA. Evaluation of surface roughness of a nanofill resin composite after simulated brushing and immersion in mouthrinses, alcohol and water. Mater Res 2010;13:77-80.
26. Badra VV, Faraoni JJ, Ramos RP, Palma-Dibb RG. Influence of different beverages on the microhardness and surface roughness of resin composites. Oper Dent 2005;30:213-9.
27. Teughels W, Van Assche N, Sliepen I, Quirynen M. Effect of material characteristics and/or surface topography on biofilm development. Clin Oral Implants Res 2006;17 Suppl 2:68-81.
28. Busscher HJ, Van Pelt AW, De Boer P, De Jong HP, Arends J. The effect of surface roughening of polymers on measured contact angles of liquids. Colloids Surf 1984;9:319-31.
29. Milosevic A. The influence of surface finish and *in vitro* pellicle on contact-angle measurement and surface morphology of three commercially available composite restoratives. J Oral Rehabil 1992;19:85-97.