Dental Research Journal

Original Article

Effects of incorporating zinc oxide and graphene oxide nanoparticles on abrasion, translucency, and microhardness of flowable composite resin: *In vitro*

Maryam Ziaei[1], Homayoun Alaghehmand[2], Ali Bijani[3], Mitra Tabari[2]

[1]Department of Pedodontics, Faculty of Dentistry, Babol University of Medical Sciences, [2]Dental Materials Research Center, Health Research Institute, Babol University of Medical Sciences, [3]Social Determinants of Health Research Center, Health Research Institute, Babol University of Medical Sciences, Babol, Iran

ABSTRACT

Background: Zinc oxide (ZnO) and graphene oxide (GO) nanoparticles (NPs) have antimicrobial properties. The present study was undertaken to evaluate the effects of incorporating these NPs and their chemical and physical blends on abrasion, translucency, and microhardness of flowable composite resin.

Materials and Methods: In the present *in vitro* study, flowable composite resin samples (Grandio Flow, VOCO, Germany) were evaluated in 5 groups and the sample size was 10 for each group of each experiment (n = 10) as follows: Group 1, without NPs; Group 2, with ZnO NPs; Group 3, with GO NPs; Group 4, containing a physical mixture of GO and ZnO; and Group 5, containing a chemical mixture of GO and ZnO NPs. In all the groups, 1 wt% of the NPs were incorporate into flowable composite resin. Abrasion, translucency, and microhardness of the samples were evaluated. Data were analyzed with analysis of variance, followed by *post hoc* Tukey's tests at the level of significance of $P < 0.05$.

Results: In Groups 2, 4, and 5 (all the groups containing ZnO), a significant decrease in abrasion and microhardness of flowable composite resin was observed compared to the control group. Incorporation of NPs in all the groups resulted in a significant decrease in translucency compared to the control group.

Conclusion: Incorporation of NPs into flowable composite resin resulted in a decrease in translucency. The microhardness was reduced in groups containing ZnO, but the abrasion was also reduced in these groups. The incorporation of GO did not significantly alter the abrasion and microhardness of the composite resin.

Key Words: Composite resins, graphene oxide, hardness, zinc oxide

Received: 20-Apr-2020
Revised: 28-Apr-2021
Accepted: 01-Jul-2021
Published: 18-Jan-2023

Address for correspondence:
Dr. Mitra Tabari,
Dental Materials Research Center, Health Research Institute, Babol University of Medical Sciences, Babol, Iran.
E-mail: mitra.tabari3@gmail.com

INTRODUCTION

Dental caries is the most common chronic childhood disease. The occlusal surface of teeth has some pits and fissures that are the most susceptible areas for the initiation and progression of caries. Recent studies have shown that almost 90% of caries in the

Access this article online

Website: www.drj.ir
www.drjjournal.net
www.ncbi.nlm.nih.gov/pmc/journals/1480

How to cite this article: Ziaei M, Alaghehmand H, Bijani A, Tabari M. Effects of incorporating zinc oxide and graphene oxide nanoparticles on abrasion, translucency, and microhardness of flowable composite resin: *In vitro*. Dent Res J 2023;20:6.

permanent teeth of children occur in pits and fissures and two-thirds of caries occur only on the occlusal surfaces of teeth.[1,2]

Preventive resin restoration is the most conservative treatment option for the restoration of pit and fissure caries and for the prevention of caries in caries-prone pits and fissures in young permanent teeth.[3-5] At present, flowable composite resins are easily used for such restorations. Other applications of flowable composite resins in pediatric dentistry are restoration of deciduous anterior teeth and restoration of cervical lesions and other small restorations that are under low stress.[6,7]

Conventionally, occlusal abrasion has been the most prevalent problem of posterior composite resins. Although it appears larger particles have higher hardness, it has been shown that larger particles accelerate abrasion. Therefore, in recent years, nanoparticles (NPs) have been introduced as fillers.[1]

For many decades, metallic oxide particles have been used as antibacterial agents in composite resins to decrease the rate of recurrent caries.[8,9] The antimicrobial properties of metals directly depend on their contact area. The dimensions of NPs allow a wide range of interactions with microorganisms, resulting in an increase in their antibacterial activity.[10] Zinc has antibacterial activity against many bacterial species, including *Streptococcus mutans*, which is one of the main bacterial species responsible for dental caries.[11] Another advantage of zinc oxide (ZnO) is its insolubility and white color. Many studies have evaluated the antibacterial effects of ZnO particles in different types of composite resin on a decrease in the rate of recurrent caries.[12,13]

Graphite NPs, which consist of carbon nanotubes, fullerene, and graphene, are considered promising agents due to their innovative properties, including antibacterial activity.[14,15] Graphene is a two-dimensional layer of Sp^2 hybrid carbon atoms with a hexagonal framework.[16] Its unique properties and prominent features include high electrical conductivity, optimal mechanical properties, large surface area, low thermal expansion coefficient, and very high aspect ratio. Previous studies have evaluated the antimicrobial properties of graphene oxide (GO) particles against both Gram-negative (*Pseudomonas aeruginosa*) and Gram-positive (*S. mutans*) bacterial species and have shown very low cytotoxicity of these particles *in vitro*.[17,18]

However, the main limitation of graphene compounds as antimicrobial agents in dentistry is their gray color and their tendency to form agglomerations when they are dispersed in a colloidal suspension. Therefore, although incorporation of GO into dental composite resins might result in an antibacterial activity,[19,17] the dark color of filler particles in visible light might affect the translucency and mechanical properties of composite resins.[10] It has been reported that it can be overcome such a problem by combining the antimicrobial properties of GO with the light color of ZnO.[17]

Considering the importance of the issues discussed above, the present study was designed to evaluate the effects of incorporating ZnO and GO NPs separately and together into flowable composite resin (Grandio) on abrasion, translucency, and microhardness of these composite resins. The null hypothesis is that examined materials have not to effect on physical and mechanical properties of composite resin.

MATERIALS AND METHODS

This *in vitro* study with the code of ethics IR.MUBABOL.HRI.REC.1397.206 was registered in the Research Institute of Health, Babol University of Medical Sciences.

Preparation of materials

In this *in vitro* study, spherical ZnO NPs, measuring 20 nm (MERCK, Germany) and layered GO NPs, with a mean size of 3.4–7 nm (MERCK, Germany) were used for mixing 0.5 wt% of ZnO with 0.5 wt% of GO.

First, for physical mixing, the ZnO solution was dissolved in methanol and chloroform and then mixed with the alcoholic solution of GO for 24 h. Then, the samples were separated with the use of solvent propagation technique in a centrifugation unit. The solvent was evaporated and the resultant precipitate was dried in an oven.

To prepare the chemical mixing, first, the ZnO NPs were dissolved in dimethyl sulfoxide solvent with the use of aminopropyltriethoxysilane, followed by agitation with the use of the ultrasonic technique. Then, the resultant precipitate was rinsed with ethanol and collected with the use of a centrifugation unit. A certain amount of the resultant precipitate was added to the GO solution in dimethylformamide solvent and allowed to take part in the chemical reaction. The chemical blend was achieved with the

use of an ultrasound unit for 2 h using the purification technique with alcohol and drying in an oven.

Preparation of specimens

Grandio flow composite resin (VOCO, Germany) shade A2 was selected for this study. One wt% from NPs with a digital scale with 0.0001 accuracies (AC Adapter, Japan) was weighed and manually with spatulation for 15 min in red-light condition on vibrator was mixed with composite resin so that homogeneity obtained.

Hence, study groups including:

1. Control group (without adding NP)
2. Containing 1 wt% ZnO NP
3. Containing 1 wt% GO
4. Containing 1 wt% physical compound of ZnO and GO
5. Containing 1 wt% chemical compound of ZnO and GO.

EDAX analysis

X-ray photoelectron spectroscopy (XPS, PHI-5702, Physical Electronics) was used to analyze homogeneity and purity percentage and level percent of materials on the surface of specimens by Al-Ka radiation as the excitation source and the bonding energy of Au (Au 4f7/2: 84.00 eV) as reference.

Abrasion test

To carry out this test, 10 samples were fabricated for each group in the form of a cube (measuring 2 mm × 10 mm × 10 mm) in a transparent mold. The samples were light-cured using a bluephase C8 (Ivoclar Vivadent) light-curing unit for 20 s. After preparation of the samples, they were stored in distilled water at room temperature for 24 h for maximum water sorption. Before abrading, the samples were thoroughly cleaned and dried. The weight of each sample was determined with the use of a digital weighing machine (AC Adapter) accurate up to 0.0001 g. The samples were placed separately in an abrading machine (PEDEB1, Babol Dentistry Research, Iran). The chrome-cobalt abrader of this machine has a cross-section of 1.12 mm^2, which delivered a 2-kg force at 5000, 10,000, 20,000, 40,000, 80,000, and 120,000 abrasion cycles on the samples. At the end of each abrasion cycle, the samples were thoroughly cleaned, dried, and weighed again. This way the amount of abrasion was determined.

Translucency test

To carry out this test, 10 composite resin disk-shaped samples were fabricated for each group, which measured 10 mm in diameter and 2 mm in thickness. All the samples were polished with the use of Soflex (3M, American) polishing disks to remove the resin-rich layer. To determine l, a and b parameters, the samples were exposed to standard D65 light in a special chamber using the easy shade machine (Vita, Germany) on a standard white and black background. The machine was calibrated before each measurement procedure. The translucency parameters were calculated and placed in the following formula:

$$\Delta E = ([l_W - l_B]^{2} + [a_W - a_B]^{2} + [b_W - b_B]^{2})^{1/2}$$

Where W and B represent the data acquired with the use of the white and black background, respectively.

Microhardness test

To carry out this test, the samples used in the translucency test were stored in distilled water at room temperature under dark conditions for 24 h. Then, they were mounted in epoxy resin and divided into two halves with the use of a disk. Then, the cut surfaces were completely polished with 400-, 800-, 1000-, 1500-, 2000-, and 2500-grit silicon carbide paper (3M, American). Then, the microhardness of the cut surfaces was determined from the surface up to the depth of the samples at 0, 0.5, 1, 1.5, and 2 mm intervals using a Vickers hardness testing machine (MH2, KOOPA Company, Iran) 3 times and their means were recorded. The force applied by the machine was 500 g, which was applied for 10 s.

Statistical analysis

The statistics consultant determined the sample size based on similar articles. One-way analysis of variance (ANOVA) followed by Tukey's *post hoc* comparison test was used to test the differences between control and experimental groups at the level of significance of $P < 0.05$ with SPSS 16 (SPSS. Inc., Chicago, IL, USA).

RESULTS

EDAX analysis

Energy-dispersive X-ray spectroscopy elemental analysis is shown in Table 1.

Abrasion

Abrasion in the GO group was not significantly different from that in the control group, except for the 10,000-round cycle in which abrasion in this group was significantly lower than that in the control group. ANOVA showed significant differences in abrasion between the study groups. Based on the results of

Tukey's tests, incorporation of ZnO NPs and physical and chemical mixtures in all the cycles resulted in a significant decrease in abrasion compared to the control group [Table 2].

According to the abrasion graph in the different cycles, two composite groups are observed; the first group is related to the control group and contains GO, which shows more abrasion. The second group is related to the ZnO-containing groups (Groups 2, 4, and 5) that show less abrasion. ZnOs presence in the composite resin seems to reduce its abrasion. This theme is not visible in the GO group [Graph 1].

Translucency

ANOVA revealed significant differences in translucency between the study groups. Based on the results of Tukey's tests, incorporation of NPs into composite resin structure in all the groups resulted in significant decreases in translucency compared to the control group [Table 3].

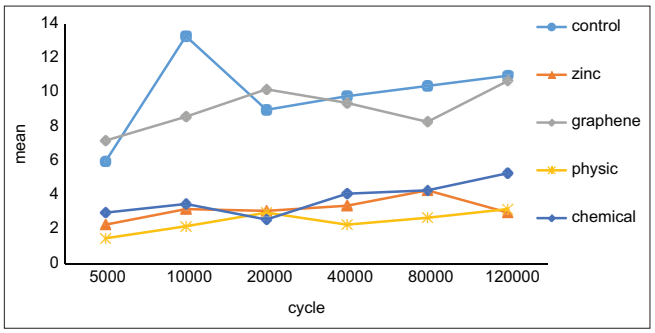
Microhardness

ANOVA showed significant differences in microhardness between all the groups. Based on the results of Tukey's tests, at depth 0 and 0.5 mm, the microhardness of the ZnO group was significantly lower than that of other groups. Incorporation of ZnO NPs and the physical compound resulted in a significant decrease in microhardness compared to the control group at 1, 1.5, and 2 mm depths. Microhardness in the GO and chemical compound group was not significantly different from the control group [Table 4].

DISCUSSION

It is obvious that antimicrobial properties are very important and useful for composite resins used for restorative purposes, especially in children. One of the techniques to confer antimicrobial properties to composite resins is to incorporate some particles into their structure.[19] ZnO[10,20] and GO[21] NPs, and their mixture[22] exhibit antimicrobial properties.

The aim of this study was to investigate the effect of adding ZnO and GO NPs on abrasion, translucency, and microhardness flowable composite resin *in vitro*.



Graph 1: Abrasion mean of groups in different cycles

Table 1: Energy dispersive X-ray spectroscopy elemental analysis to the weight percentage of composite resin discs

Elements	Groups				
	Control	Zinc oxide	Graphene oxide	Physical compound	Chemical compound
C	36.02	32.38	37.34	33.66	35.68
O	36.3	40.99	39.96	39.92	39.89
Al	3.51	3.79	3.9	3.32	3.5
Si	18.94	19.13	16.02	18.55	17.89
Ba	5.23	3.29	2.78	4.16	2.69
Zn	-	0.42	-	0.39	0.35

Table 2: The results of abrasion test in different cycles

Cycles	Abrasion×10^{-4}					*P**
	Control±SD	Zinc oxide±SD	Graphene oxide±SD	Physical compound±SD	Chemical compound±SD	
5000	6.00±2.582[a]	2.30±1.636[b]	7.20±3.259[a]	1.50±0.850[b]	3.00±1.826[b]	<0.001
10,000	13.30±3.561[a]	3.20±2.044[b]	8.60±2.836c	2.20±1.033[b]	3.50±1.841[b]	<0.001
20,000	9.00±4.110[a]	3.10±2.132[b]	10.20±5.224[a]	3.00±1.491[b]	2.60±1.838[b]	<0.001
40,000	9.80±3.967[a]	3.40±1.430[b]	9.40±3.836[a]	2.30±1.829[b]	4.10±1.912[b]	<0.001
80,000	10.40±3.406[a]	4.30±1.494[b]	8.30±3.683[a]	2.70±1.947[b]	4.30±1.252[b]	<0.001
120,000	11.00±3.944[a]	3.00±1.333[b]	10.70±4.572[a]	3.20±1.033[b]	5.30±3.335[b]	<0.001

Small letters indicate significant differences in abrasion between the different study groups in which nanoparticles were incorporated into composite resin structure ($P<0.05$). SD: Standard deviation

According to searches, no similar study has been found so far.

An *in vitro* study cannot simulate all the conditions of the oral cavity. On the other hand, clinical studies on the abrasion of restorative materials are time consuming, costly, and more complicated than *in vitro* studies in relation to the procedural steps. Therefore, the present study was evaluated *in vitro*.[23,24] However, due to differences in laboratory conditions, the results of different studies cannot easily be compared.[25]

There are several ways to estimate of abrasion resistance. In the present study, the weight loss method was used.

Various studies have reported that the abrasion rate of flowable composite resin is higher than other composites. Clelland *et al*. reported that flowable composite reins exhibited more abrasion compared to the highly filled composite resins in the microfilled and microhybrid categories.[26] In the present study, too, abrasion of flowable composite resin was higher in the control group in which NPs were not incorporated into the structure of composite resin, compared to the other groups.

Recent studies have shown that it is possible to improve the physical properties of flowable composite resins by increasing in volume and decreasing in size of the filler content.[27] Since the particle size is correlated with microhardness, roughness, and other properties, it has been suggested that the use of NPs results in better mechanical properties, including compression, fracture resistance and flexural strength, and improved surface properties, including higher surface luster and resistance to abrasion.[28] Kumar *et al*. reported that theoretically larger particles might result in greater abrasion of restorative materials.[29]

The results of the present study showed that incorporation of ZnO NPs, physical mixture, and chemical blend resulted in a decrease of abrasion in all the cycles; however, the amount of abrasion in the GO group did not differ significantly from the control group and was lower in the 10,000 cycle alone. The presence of ZnO NPs in these groups (ZnO groups, physical composition, and chemical composition) seems to have reduced abrasion. GO particles have a layered structure, and the lack of adhesion between the GO layers and the composite resin may not increase the abrasion resistance of the composite resin.

The reasons for a decrease in abrasion might be attributed to factors such as the type of matrix and resin, the size, shape and distribution of filler particles, silanization, hardness of the filler, and degree of conversion of composite resins.[27,30] A decrease in particle size and an increase in the filer content resulted in a decrease in abrasion.[31] Wang *et al*. reported that nanofilled composite resins exhibited higher resistance to abrasion compared to hybrid composite resins.[32]

Based on previous studies, the filler content of composite resins affects abrasion. The filler content has an indirect relationship with abrasion and an increase in filler content results in a decrease in abrasion, which might be explained by a lower surface area of the resin unprotected by filler particles.[30] Contrary to the results of the present study, Yesil *et al*. reported that an increase in the filler content in nanocomposite resins did not improve the abrasion rate,[33] which might be due to the fact that the composite resin used

Table 3: The results of translucency test

Groups	*n*	Mean±SD	Minimum-maximum	*P*
Control	10	13.2680±0.576^{a}	12.38-13.98	<0.001
Zinc oxide	10	10.5680±0.917^{b}	9.23-11.70	
Physical compound	10	8.9530±0.705^{c}	8.00-9.75	
Chemical compound	10	8.0060±0.473^{d}	7.39-8.73	
Graphene oxide	10	4.7340±0.591^{h}	3.81-5.56	

Small letters indicate significant differences in translucency between the different study groups in which nanoparticles were incorporated into composite resin structure (P<0.05). SD: Standard deviation

Table 4: The results of microhardness test at different depths of composite resin

Depth (mm)	Hardness					*P**
	Control±SD	Zinc oxide±SD	Graphene oxide±SD	Physical compound±SD	Chemical compound±SD	
0	174.10±7.400$^{a, b}$	157.20±8.404^{c}	175.20±8.351^{a}	163.30±9.684^{bc}	167.80±9.041^{a,b,c}	<0.001*
0.5	174.70±9.274$^{a, b}$	158.60±8.746^{c}	177.60±8.720^{a}	163.60±10.058^{bc}	168.50±8.860^{a,b,c}	<0.001*
1	177.40±8.695^{a}	160.50±9.046^{b}	180.10±8.724^{a}	165.90±9.422^{b}	171.50±8.657^{a,b}	<0.001*
1.5	180.40±8.422^{a}	162.90±9.255^{b}	182.90±8.863^{a}	168.30±9.569^{b}	173.40±8.834^{a,b}	<0.001*
2	183.30±8.084^{a}	165.80±9.065^{b}	186.50±9.595^{a}	170.70±9.615^{b}	176.90±8.386^{a,b}	<0.001*

Small letters indicate significant differences in microhardness between the different study groups in which nanoparticles were incorporated into composite resin structure (P<0.05). SD: Standard deviation

in that study was not flowable; therefore, the amount of change in abrasion was not significant.

In the present study, the colorimetry technique with the use of a spectrophotometer was applied to determine color changes. In addition, since based on the objective CIELAB system, the l, a and b parameters are suitable for research studies and for quantitative evaluation of color changes;[34] in the present study, all these parameters were evaluated separately. In fact, ΔE describes color changes with the use of l, a and b parameters and ΔE>3.3 is considered significant color change clinically.[35,36] In fact, ΔE>3.3 is considered as the threshold for perceiving color changes by the eyes of laypeople.[6]

In the present study, translucency in the GO, the physical and chemical composition compared to the control group were >3.3 and in the ZnO group, it was <3.3. Therefore, only in the ZnO group could not be detected changes in translucency by the eyes of laypeople ($\Delta E_{Control} - \Delta E_{ZnO} = 2.8$).

Brandão *et al*. reported that the translucency of composite rein containing ZnO NPs depends on the concentration, decreasing with an increase in concentration. Therefore, translucency is negatively affected by ZnO NPs. An increase in the concentration of ZnO NP concentration resulted in a decrease in the degree of conversion of the tested adhesives. Most probably, a decrease in the translucency of composite reins with a higher ZnO-NP contact is due to the dissimilarity between the fracture index of Bis-GMA: TEGDMA complex and ZnO-Np.[37]

Hardness is an internal property of materials and depends on the composition and microstructure of the material. In addition, it should be noted that an increase in filler quality does not necessarily result in an increase in hardness because hardness depends on other factors including the type and quality of silanization and modification of the filler surface, too.[28]

In the present study, incorporation of GO NPs into flowable composite resin resulted in an increase in microhardness compared to the control group, which was not significant.

Sava *et al*. reported that incorporation of 5–10 wt% of a mixture of hydroxyapatite and GO NPs into the matrix monomer of composite resin resulted in an increase in surface hardness, young modulus, and flexural strength.[38]

In the present study, incorporation of ZnO NPs and a physical mixture of NPs into flowable composite resin resulted in a significant decrease in microhardness compared to the control group. Panahandeh *et al*. reported that incorporation of nanorod ZnO particles did not result in any change in the surface hardness of glass ionomer; however, incorporation of nanospherical and nanoflower ZnO particles resulted in a significant decrease in surface hardness of glass ionomer compared to the control group.[39] In the present study, nanospherical ZnO particle was used. Brandão *et al*. reported that an increase in the concentration of ZnO NPs from 0% to 5% resulted in a decrease in microhardness.[37] The results of a study by Garcia *et al*. showed a decrease in hardness after incorporating ZnO NPs into the adhesive, which might be explained by agglomeration of NPs in the adhesive resin.[40]

Tavassoli *et al*. showed that incorporation of ZnO NPs into flowable composite resin resulted in improvements in its compressive strength, flexural module, and bond strength, in addition to its antibacterial properties, with no effect on flexural strength and compressive module.[10]

Considering a paucity of studies on the physical and mechanical properties of composite resins containing GO and ZnO NPs, further studies are necessary to evaluate the effects of these NPs on other mechanical and physical properties of flowable composite resin.

CONCLUSION

Incorporation of NPs into flowable composite resin resulted in a decrease in translucency. The microhardness was reduced in groups containing ZnO, but the abrasion was also reduced in these groups. The incorporation of GO did not significantly alter the abrasion and microhardness of the composite resin.

Financial support and sponsorship
Nil.

Conflicts of interest
The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

REFERENCES

1. Arthur JN. Pediatric Dentistry Infancy through Adolescence. 6th ed. Missouri: Elsevier; 2019. p. 916.
2. Jeffrey AD. McDonald and Avery's Dentistry for the Child and

Adolescent. 10th ed. Mosby: Elsevier; 2016. p. 181.
3. McComb D. Systematic review of conservative operative caries management strategies. J Dent Educ 2001;65:1154-61.
4. Peumans M, Kanumilli P, De Munck J, Van Landuyt K, Lambrechts P, Van Meerbeek B. Clinical effectiveness of contemporary adhesives: A systematic review of current clinical trials. Dent Mater 2005;21:864-81.
5. Simonsen RJ. Preventive resin restorations and sealants in light of current evidence. Dent Clin North Am 2005;49:815-23, vii.
6. Sakaguchi RL, Powers JM. Craig's Restorative Dental Materials. 13th ed. St. Louis, Mo: Elsevier/Mosby; 2012. p. 164-6.
7. Autio-Gold JT. Clinical evaluation of a medium-filled flowable restorative material as a pit and fissure sealant. Oper Dent 2002;27:325-9.
8. Lansdown AB. Silver in health care: Antimicrobial effects and safety in use. Curr Probl Dermatol 2006;33:17-34.
9. Phan TN, Buckner T, Sheng J, Baldeck JD, Marquis RE. Physiologic actions of zinc related to inhibition of acid and alkali production by oral streptococci in suspensions and biofilms. Oral Microbiol Immunol 2004;19:31-8.
10. Tavassoli HS, Alaghemand H, Hamze F, Ahmadian BF, Rajab-Nia R, Rezvani MB, *et al.* Antibacterial, physical and mechanical properties of flowable resin composites containing zinc oxide nanoparticles. Dent Mater 2013;29:495-505.
11. Beyth N, Domb AJ, Weiss EI. An *in vitro* quantitative antibacterial analysis of amalgam and composite resins. J Dent 2007;35:201-6.
12. Hernández-Sierra JF, Ruiz F, Pena DC, Martínez-Gutiérrez F, Martínez AE, Guillén Ade J, *et al.* The antimicrobial sensitivity of *Streptococcus mutans* to nanoparticles of silver, zinc oxide, and gold. Nanomedicine 2008;4:237-40.
13. Niu LN, Chen JH, Fang M, Yang JC, Xiao YH, Ni F. Effects of three different zinc oxide incorporation on the antibacterial activity against *Streptococcus mutans* of composite resin. Hua Xi Kou Qiang Yi Xue Za Zhi 2009;27:210-2.
14. Olivi M, Zanni E, De Bellis G, Talora C, Sarto MS, Palleschi C, *et al.* Inhibition of microbial growth by carbon nanotube networks. Nanoscale 2013;5:9023-9.
15. Akhavan O, Ghaderi E. Photocatalytic reduction of graphene oxide nanosheets on TiO2 thin film for photoinactivation of bacteria in solar light irradiation. J Phys Chem 2009;113:20214-20.
16. Priyadarsini S, Mukherjee S, Mishra M. Nanoparticles used in dentistry: A review. J Oral Biol Craniofac Res 2018;8:58-67.
17. Zanni E, De Bellis G, Bracciale MP, Broggi A, Santarelli ML, Sarto MS, *et al.* Graphite nanoplatelets and Caenorhabditis elegans: Insights from an *in vivo* model. Nano Lett 2012;12:2740-4.
18. Rago I, Bregnocchi A, Zanni E, D'Aloia A, De Angelis F, Bossu M, *et al.*, editors. Antimicrobial Activity of Graphene Nanoplatelets against *Streptococcus mutans*. In: 2015 IEEE 15th International Conference on Nanotechnology (IEEE-NANO). Rome, Italy, IEEE; 2015.
19. Aydin Sevinç B, Hanley L. Antibacterial activity of dental composites containing zinc oxide nanoparticles. J Biomed Mater Res B Appl Biomater 2010;94:22-31.
20. Fang M, Chen JH, Xu XL, Yang PH, Hildebrand HF. Antibacterial activities of inorganic agents on six bacteria associated with oral infections by two susceptibility tests. Int J Antimicrob Agents 2006;27:513-7.
21. He J, Zhu X, Qi Z, Wang C, Mao X, Zhu C, *et al.* Killing dental pathogens using antibacterial graphene oxide. ACS Appl Mater Interfaces 2015;7:5605-11.
22. Kulshrestha S, Khan S, Meena R, Singh BR, Khan AU. A graphene/zinc oxide nanocomposite film protects dental implant surfaces against cariogenic Streptococcus mutans. Biofouling 2014;30:1281-94.
23. Hu X, Marquis PM, Shortall AC. Influence of filler loading on the two-body wear of a dental composite. J Oral Rehabil 2003;30:729-37.
24. Mehl C, Scheibner S, Ludwig K, Kern M. Wear of composite resin veneering materials and enamel in a chewing simulator. Dent Mater 2007;23:1382-9.
25. DeLong R. Intra-oral restorative materials wear: Rethinking the current approaches: how to measure wear. Dent Mater 2006;22:702-11.
26. Clelland NL, Pagnotto MP, Kerby RE, Seghi RR. Relative wear of flowable and highly filled composite. J Prosthet Dent 2005;93:153-7.
27. Tsujimoto A, Barkmeier WW, Fischer NG, Nojiri K, Nagura Y, Takamizawa T, *et al.* Wear of resin composites: Current insights into underlying mechanisms, evaluation methods and influential factors. Jpn Dent Sci Rev 2018;54:76-87.
28. Rodríguez HA, Casanova H. Effects of silica nanoparticles and silica-zirconia nanoclusters on tribological properties of dental resin composites. J Nanotechnol 2018;2018:1-10.
29. Kumar SR, Patnaik A, Bhat IK. Factors influencing mechanical and wear performance of dental composite: A review. Mater Sci Eng Technol 2020;51:96-108.
30. Cao L, Zhao X, Gong X, Zhao S. An *in vitro* investigation of wear resistance and hardness of composite resins. Int J Clin Exp Med 2013;6:423-30.
31. Yilmaz E. Investigating the effect of chewing force and an abrasive medium on the wear resistance of composite materials by chewing simulation. Mech Compos Mater 2020;56:261-8.
32. Wang LK, Shi LS, Zhu HS. An *in vitro* investigation of wear resistance and hardness of three kinds of new composite resins. Hua Xi Kou Qiang Yi Xue Za Zhi 2008;26:15-8.
33. Yesil ZD, Alapati S, Johnston W, Seghi RR. Evaluation of the wear resistance of new nanocomposite resin restorative materials. J Prosthet Dent 2008;99:435-43.
34. Johnston WM. Color measurement in dentistry. J Dent Mater 2009;37:e2-6.
35. Gomes MN, Francci C, Medeiros IS, De Godoy Froes Salgado NR, Riehl H, Marasca JM, *et al.* Effect of light irradiation on tooth whitening: Enamel microhardness and color change. J Esthet Restor Dent 2009;21:387-94.
36. Soares DG, Basso FG, Pontes EC, Garcia Lda F, Hebling J, de Souza Costa CA. Effective tooth-bleaching protocols capable of reducing H_2O_2 diffusion through enamel and dentine. J Dent 2014;42:351-8.
37. Brandão NL, Portela MB, Maia LC, Antônio A, Silva VLME, Silva EMD. Model resin composites incorporating ZnO-NP: Activity against S. mutans and physicochemical properties characterization. J Appl Oral Sci 2018;26:e20170270.

38. Sava S, Moldovan M, Sarosi C, Mesaros A, Dudea D, Alb C. Effects of graphene addition on the mechanical properties of composites for dental restoration. Mater Plast 2015;52:90-2.
39. Panahandeh N, Torabzadeh H, Aghaee M, Hasani E, Safa S. Effect of incorporation of zinc oxide nanoparticles on mechanical properties of conventional glass ionomer cements. J Conserv Dent 2018;21:130-5.
40. Garcia IM, Leitune VC, Kist TL, Takimi A, Samuel SM, Collares FM. Quantum dots as nonagglomerated nanofillers for adhesive resins. J Dent Res 2016;95:1401-7.