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Original Article

The effect of adding silver nanoparticles on the color stability of feldspathic porcelains

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ABSTRACT

Background: This study aims to investigate the color stability of feldspathic porcelains with different concentrations of silver nanoparticles (AgNPs).

Materials and Methods: In this experimental study, feldspathic porcelain disks with AgNPs of 0 parts per million (ppm), 250 ppm, and 500 ppm were used (sample size = 180). These ceramic discs were subjected to thermocycling in tea, orange juice, and artificial saliva. The optical parameters of disks were measured before and after being immersed in the solutions. Then, the color change (ΔE 00) of the samples was measured by using the CIEDE 2000 formula. The data were analyzed by one-way analysis of variance (ANOVA) and Tukey's *post hoc* test. The level of significance was determined to be 0.05.

Results: The results of the ANOVA test show that there was a significant difference in ΔE 00 ($P \leq 0.05$). The maximum ΔE 00 was visible in the samples with AgNPs 0 ppm that were exposed to orange juice, and the minimum ΔE 00 was related to the disks with AgNPs 500 ppm in artificial saliva.

Conclusion: Based on the results of this study, adding AgNPs to feldspathic porcelain increases the color stability of the ceramic discs.

Key Words: Color, dental porcelain, nanoparticles, silver, tooth discoloration

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INTRODUCTION

Dental porcelains are widely used in fixed restoration due to their high biocompatibility, mechanical durability, and aesthetics, similar to natural teeth.[1] However, under the excessive occlusal forces of these materials, they may suffer from chipping or fracture due to the lack of malleability and elongation; therefore nowadays, dental porcelains are modified using metal oxide nanoparticles to improve fracture toughness and prevent crack propagation.[2] In studies to improve the properties of feldspathic porcelain, various nanomaterials, including silver, zirconia (ZrO_2), alumina (Al_2O_3), hydroxyapatite (HA), titanium dioxide (TiO_2), and platinum have investigated.[2]

Silver is an antibacterial substance that can kill many pathogenic microorganisms. Nowadays, silver nanoparticles (AgNPs) are widely used in medicine,

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dentistry, and pharmacy due to their physical and biochemical properties.[3]

Karthikeyan *et al*. evaluated the biocompatibility of feldspathic porcelain containing different concentrations (5%, 10%, 20%, and 30%) of silver ion nanoparticles. They concluded that the addition of these nanoparticles to the porcelain mixture in laboratory conditions increases cell activity and has significant antimicrobial activity against Streptococcus Mutans bacteria (especially porcelain containing 30% of AgNPs).[4]

Hashem *et al*. investigated the fracture strength and color of dental ceramics after adding AgNPs and HA. These nanoparticles were added to a concentration of 40 µg/ml and compared with the control group without nanoparticles. They concluded that the addition of AgNPs increases the fracture strength of ceramics, but the addition of HA, on the contrary, decreases the fracture strength. However, the addition of both of these nanoparticles harms the color of dental ceramics.[5]

Ceramic materials are a good choice for replacing anterior and posterior teeth. However, changing the color of the restoration over time is a challenge that endangers the beauty of the appearance.[6]

The concern of patients about the restoration causes even tiny color changes to lead to dissatisfaction and replacement of the restoration, the overall result of which is spending money, wasting the patient's time, and even damaging the dental structure.[7] In some recent studies, the effect of adding AgNPs on the color changes of feldspathic porcelains has been investigated.[8]

Firoz *et al*. investigated the effect of adding AgNPs on the optical behavior of feldspathic porcelains; based on the results of this study, adding AgNPs up to 500 µg/ml to feldspathic porcelains caused a color change (ΔE) beyond the clinically detectable threshold ($\Delta E = 2.69$) and increases the translucency of the ceramic.[9]

Consuming acidic foods and fruits as well as drinks causes dental erogenous. This erosion occurs in enamel due to the dissolution of HA crystals. Laboratory studies have also shown that cola, juices, and acidic drinks can all cause significant changes in the color of dental restorative materials.[10]

In this study, we aim to investigate the color stability of feldspathic porcelains containing different concentrations of AgNPs in tea, orange juice, and artificial saliva, which has not been investigated in any study before. The null hypothesis was that there is no significant effect on the color stability of the feldspathic porcelain disks due to adding AgNPs.

MATERIALS AND METHODS

Synthesis of silver nanoparticles

In this study, AgNPs were made using a green synthesis process. First, pomegranate fruit was procured from the local market (Hamadan, Iran). The fruit skin was dried in an oven at a temperature of 60°C and then its powder was prepared. 10 g of the prepared powder mixed with 100 ml of ethanol/water (30:70) solution for 24 h, and then filtered. After evaporating the solvent under a temperature of 40°C using a rotary machine (Heidolph, Germany), it was mixed in 50 ml of distilled water and then passed through Whatman paper. The pomegranate peel extract was kept at 4°C. To prepare AgNPs, an aqueous solution of silver nitrate (AgNO3) and prepared pomegranate peel extract were slowly added to it. The color change of the solution to brown-yellow indicated the successful synthesis of AgNPs. After preparing the AgNPs sample powder, it was sent to the Par Tavos Research Institute in Mashhad to check the size morphology of the synthesized nanoparticles; The sample was examined at a temperature of 20°C and in the measurement range of 31X-680KX by an electron microscope (TEM) model CM120 (Philips PW1730, Netherlands).

To check the crystal structure and constituent units of nanoparticles using x-ray diffraction (X'Pert, Philips PW1730, Netherlands-XRD), the powder sample of synthesized nanoparticles was sent to Par Tavos Company from Mashhad.

Sample size and sample preparation

The present research is an experimental study. The sample size in the current study was 180, and we had 9 groups, which 20 samples were randomly placed in each group. In this study, feldspathic porcelain with color 2 m1 (Vita VM9, Vita Zahnfabric, Bad Säckingen, Germany) was used. For the preparation of ceramic discs with dimensions of 20 mm × 1 mm, a resin (Pattern Resin LC, GC America) model of these dimensions was prepared, then using it, a mold was prepared using polyvinyl siloxane (Panasil, Kettenbach Co., Germany). The synthesized AgNPs were added to pure distilled water with the help of carboxymethyl cellulose to distribute the particles uniformly. Then, we shaped ceramic discs using distilled water containing AgNPs of 0 ppm, 250 ppm, and 500 ppm. After mixing the powder and molding liquid, the porcelain paste was placed in the mold with a wet brush. They were subjected to sintering according to the manufacturer's recommendation. Finally, the ceramic disks were finished. Then they polished using sandpaper with particle sizes of 320, 600, 1200, and 2400, respectively.

The thickness of the samples was controlled using a digital caliper. Samples with any structural defects and defects in size and diameter were excluded from the study. The samples were ultrasonically cleaned (EUROSONIC 4D-Italy) for 10 min in distilled water before color measurement.

The measurement of optical parameters (a*, b*, and L coordinates) before and after thermocycling.

The measurement of the optical parameters was done by a spectrophotometer (Vita easy shade compact, Zahnfabrik, Germany). A positioning jig was used to measure the values of a*, b*, and L in the central part of each sample. The measurement was also repeated three times for each parameter and then we considered the average of them.[11] A 50% gray background[12] was used under each sample.

Thermocycling of samples

Samples in the artificial saliva group were incubated at 37°c for 125 h. Samples in tea and orange juice were immersed in the respective solutions and subjected to 3000 thermal cycles in a thermocycler (MSCT-3; Convel) for aging. One container contained 37°c artificial saliva, and another contained the respective solution at 5°c for orange juice or 55°C for tea.

Measurement of the color change of samples

The following formula used to calculate the changes in the final color (ΔE_{00}) and value change (ΔL):[13]

$$\Delta E_{\infty} = \sqrt{\left(\frac{\Delta L'}{K_L\, S_L}\right)^2 + \left(\frac{\Delta C'}{K_C\, S_C}\right)^2 + \left(\frac{\Delta H'}{K_H\, S_H}\right)^2 + R_T \frac{\Delta C'}{K_C\, S_C}\frac{\Delta H'}{K_H\, S_H}}$$

$$\Delta L = L_{2\ (\text{after})} - L_{1\ (\text{before})}$$

Data analysis

Statistical analysis of the data was done by SPSS Statistics v 22.0 (SPSS Inc., Chicago, Illinois, United States) and their normal distribution was analyzed by Kolmogorov–Smirnov and Shapiro–Wilk tests ($P > 0.05$). One-way analysis of variance (ANOVA) was used, and pairwise comparisons of groups were performed by Tukey HSD *post hoc* test. The level of significance was determined to be 0.05.

RESULTS

One-sample Kolmogorov–Smirnov test was used to check the normal distribution of data. The results of this test showed that the ΔE 00 and ΔL parameters have a normal distribution ($P > 0.05$). Therefore, a one-way ANOVA was used to compare variables among the groups. The mean and standard deviation of the ΔE 00 and ΔL, and results of the ANOVA test for the studied groups are visible in Table 1.

Since the mean values of the ΔE 00 and ΔL in tea, orange juice, and artificial saliva had statistically significant differences among the studied groups ($P < 0.05$); Tukey HSD *post hoc* test was used for pairwise comparison among the groups.

According to the pairwise comparison of ΔE00 and ΔL in different concentrations of AgNPs, significant statistical differences ($P < 0.05$) have been observed between each of the subgroups of tea, orange juice,

Table 1: One-way analysis of variance results and the average color change (ΔE_{00}) and also the value change (ΔL) of porcelain samples with different concentrations of silver nanoparticles in different solutions are visible

Solutions	Color parameters	AgNPs (ppm)	Mean	SD	*P*-value between groups
Tea	ΔE_{00}	500	1.17	0.31	0.001
		250	1.46	0.25	
		0 (control)	3.00	0.59	
	ΔL	500	0.95	0.24	0.001
		250	1.22	0.25	
		0 (control)	2.64	0.63	
Orange	ΔE_{00}	500	1.18	0.35	0.001
		250	1.67	0.32	
		0 (control)	3.88	0.43	
	ΔL	500	1.01	0.32	0.005
		250	1.42	0.35	
		0 (control)	3.28	0.43	
Artificial saliva	ΔE_{00}	500	0.48	0.27	0.001
		250	0.60	0.18	
		0 (control)	1.48	0.27	
	ΔL	500	0.28	0.20	0.001
		250	0.35	0.179	
		0 (control)	0.98	0.28	

ppm: Parts per million; SD: Standard deviation; AgNPs: Silver nanoparticles and artificial saliva; the exception of this is the comparison between the two subgroups of tea with AgNPs 500 ppm and 250 ppm that no statistically significant change was detected.

As shown in Figure 1, the maximum color change occurred at the concentration of 0 ppm AgNPs in orange juice, and the minimum color change is related to the porcelains containing a concentration of 500 ppm of silver in artificial saliva.

In this investigation, ΔE00 values were compared with a 50:50% acceptability threshold (ΔE00 = 1.8), and a 50:50% perceptibility threshold (ΔE00 = 0.8). Therefore, ΔE00 values were 0.8, and ΔE00 >0.8 was considered as a clinically perceptible color difference; furthermore, the ΔE00 value was 1.8, and ΔE00 >1.8 designated as a clinically unacceptable color difference.[13]

DISCUSSION

According to the results of this study, the null hypothesis is rejected. Furthermore, according to the results, adding AgNPs to the studied feldspathic porcelain makes the color of this porcelain more stable when exposed to colored solutions.

In this study, the green method of AgNP synthesis was used because of more environmentally friendly, less expensive, and more biocompatible than other synthesis methods, and the reduction and stabilization of reducing agents.[1,9,14,15]

Positioning jig used during measurement of a*, b*, and L with two goals. The first goal is to eliminate the effect of ambient light, and the second goal is to unify the measured points in the samples.[16]

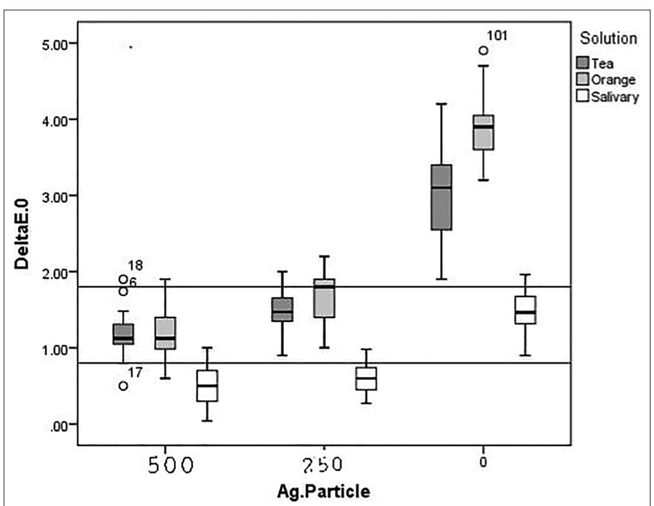

Figure 1: Box plot diagram of the amount of color change (ΔE_{00}) and comparing ΔE_{00} with the acceptability (upper horizontal line) and perceptibility (lower horizontal line) thresholds.

Based on different reports, the CIEDE2000 formula exhibits superior balancing for determining color changes. The superiority in the color change evaluation with the CIEDE2000 is related to the uniformity in the evaluations compared to the CIELAB formula.[17,18] In addition, different investigations have reported that the CIEDE2000 ensures an excellent correlation between the perceived and evaluated color changes.[19-22] Considering the above, the CIEDE2000 formula was used to specify the color change values in the current study.

An optical liquid with a refraction index of approximately 1.5 was added to improve the accuracy of spectrophotometric evaluation by reducing "edge-loss."[23,24] Edge loss is a phenomenon in which light scattered through a translucent material ordinarily would be seen by the eye but is not measured by the instrument. This happens when the light is scattered in the translucent object away from the aperture and does not return through the aperture to the sensor; the phenomenon is wavelength dependent.[24]

According to the results obtained in this study, by increasing the concentration of AgNPs from 0 ppm to 500 ppm in the solutions used for immersing the porcelain disks, the ΔE00 and ΔL decrease. This phenomenon can probably be due to the reduction of porosity of porcelain disks due to the formation of silver oxide in the structure of ceramics. Furthermore, according to the study of Vazquezz-Garcia *et al.*, adding AgNPs to calcium carbonate cement reduces the porosity of these types of cement,[25] which is in accordance with the results of our study. Furthermore, adding silver to the dental porcelains will strengthen the fracture toughness,[26] increase the fatigue parameter,[27] reduce the crack depth,[28] and increase the fracture strength[5] of the porcelains. Therefore, according to previous studies, it is visible that adding silver to the structure of porcelains can solve the mechanical problems of these materials.

In this study, we used concentrations of 0 ppm, 250 ppm, and 500 ppm AgNP. Disks with a concentration of 0 ppm were considered as the control group, and the reason for using concentrations of 250 ppm and 500 ppm was a previous study,[29] according to which dental porcelains show clinically unacceptable color changes with AgNPs higher than 500 ppm. According to the results of the pairwise comparison of ΔE 00 and ΔL parameters, there is a significant statistical difference between all subgroups of each of the solutions ($P < 0.05$), except for concentrations of 250 ppm and 500 ppm in tea. The highest amount of color and value change was related to the subgroup of orange juice solution with 0 ppm AgNPs (ΔE 00 = 3.88 and ΔL = 3.28), which can be considered probably due to the low pH of orange juice solution (PH = 3) and the effect of this solution on the surface layer of ceramic disks. Also, this amount of color change is considered clinically unacceptable. Also, the simultaneous effect of acidic pH and yellow pigments in the orange juice can cause this amount of color change. These findings are in accordance with the study of Hipólito *et al*. In their study, the PH of solutions in which ceramics are immersed affects the magnitude of color change.[30] In the orange juice group, with the increase in the concentration of AgNPs, the amount of ΔE 00 returns to the clinically acceptable range (ΔE 00 of 250 ppm AgNPs in the orange juice group was 1.67, and this amount of 500 ppm was 1.18), which can indicate the effect of AgNPs on the color stability of porcelain discs [Figure 1].

Destruction of the superficial layer of ceramic occurs following exposure to low PH, leading to silica dissolution and loss of alkaline ions.[31] Thus, the ceramic becomes susceptible to penetration of different pigments.

Concerning porcelain disks immersed in tea, the amount of ΔE 00 at 0 ppm concentration of AgNPs is not clinically acceptable (ΔE 00 = 3), which is similar to the orange juice solution, with the increase in the concentration of AgNPs, the amount of ΔE 00 decreases (ΔE 00 of 250 ppm AgNPs on tea group was 1.46 and this amount of 500 ppm was 1.17) and returns to the clinically acceptable range [Figure 1]. The amount of color change observed in the tea group is less than in the orange juice group, which can be attributed to the different pH of these two solutions (PH of tea is 4.9).

The lowest amount of ΔE 00 was observed in the concentration of 500 ppm AgNPs in artificial saliva, which increases with the reduction of AgNPs. However, in all concentrations, the amount of color change is under the clinically acceptable range. The lowest amount of color change can be observed in artificial saliva due to the high pH of this solution and the absence of colored pigments (PH of artificial saliva is 6.3).

One of the limitations of this research was the lack of similar studies. For future studies, the effect of AgNPs on different porcelains and different colored solutions is suggested.

CONCLUSION

Based on the results of this study, the following results can be mentioned:

1. AgNPs significantly increase the color stability of feldspathic ceramics
2. The color (ΔE 00) and value change (ΔL) of feldspathic ceramics decrease with the increase of AgNPs when exposed to the studied solutions.

Ethical approval

This study was approved by Hamadan University of Medical Sciences (Ethics No. IR. UMSHA. REC.1400.600).

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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.

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