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Original Article

The Effect of Hybrid Nano Addition on the Color Stability of Maxillofacial Rehabilitation Silicone Material after Weathering

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Abstract

Background: Facial prostheses may get discolored and change color from intrinsic and extrinsic coloring due to external factors. This is related to the inherent color stability of elastomers and colorants. **Objectives:** We aimed to evaluate the effect of hybrid nano additives on the color stability of Tech-Sil25 room-temperature vulcanized silicones used for maxillofacial prosthesis after artificial weathering. **Materials and Methods:** A total of 70 samples were fabricated for fourteen groups. Seven groups contained 0.2 wt% burnt sienna, and another seven groups contained 0.2 wt% cobalt blue. The seven groups were the control groups. Each group consists of five samples. The samples were exposed to artificial weathering for 300 h. The CIELAB color system was used to record the color values. It aids in the numerical classification of color differences by describing the three color coordinates (or color values) x, y, and z in three unique corresponding values of L, a, and b, respectively. **Results:** Burnt sienna pigment samples with hybrid nano 1%NS+1%NA show the highest color stability, followed by 2% NS and 2% NA; the least color change was observed (ΔE^* about = 1.1) by the visual system as the threshold was seen. The cobalt blue pigment shows the most significant color change. The color shift observed in all groups was within the clinically acceptable level. **Conclusion:** It can be concluded that a 2% hybrid nano additive can improve the color stability for both pigment groups (burnt sienna and cobalt blue). The variation in color in the burnt sienna group was less than that in the cobalt blue groups. The color change in each group came within an acceptable range for clinical purposes.

Keywords: Color changes, hybrid nano, maxillofacial rehabilitation, weathering

Introduction

Extraoral craniofacial prostheses are used to repair face deformities brought on by inherited disorders such as cancer or trauma as well as acquired disorders such as cancer; they may be used alone or in conjunction with plastic surgery, and these prostheses significantly enhance a patient's quality of life by restoring not just function but also the esthetics.[1] The extraoral parts of the maxillofacial prosthesis have traditionally been made of silicone. These materials are strong, inert to chemical agents, biocompatible, and simple to work with.[2]

Although aesthetics and color stability are crucial factors for the clinical effectiveness of craniofacial prostheses, their short service life due to deterioration and color instability is a significant issue.[3] According to reports, the most frequent reason that patients are unhappy with their prostheses is due to the color changes.[4] Environmental elements may have a negative impact on silicone's mechanical qualities and appearance, including sunlight exposure, humidity, air pollution, cleaning chemicals and techniques, cosmetic and skincare products, and sweat. Exposure to ultraviolet (UV) light is a significant element that might cause damage and discoloration in the facial region of prosthetics, requiring replacement more often and increasing treatment expenses.[4,5]

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By absorbing the radiation of UV photons, polymers like silicone elastomers may break their chains and create new radicals that might further deteriorate polymer networks, resulting in a molecular weight decrease, a loss of adaptability, a reduction in mechanical capabilities, surface cracking, loss of shine, discoloration, and fading, which are all potential effects of this procedure.[6] The color instabilities of silicone prosthetics are caused by factors inherent to the silicone and the pigments themselves, as well as environmental factors, including adsorption as well as absorption, processing heat, the color of the manufacturing stone, use of the adhesive, exposure to bodily fluids and cosmetic chemicals, cleaning technique effects, and handling by patients.[7]

Nano-oxide materials have been introduced into polymers as reinforcement materials and for UV damage prevention.[8] Their high chemical reactivity allows them to interact with and maintain the polymer chains, which endows them with their reinforcing mechanism.[9] It has been hypothesized that the small size of nano-oxides increases their UV absorbing capacity and permits UV light dispersion, which lowers the overall amount of UV energy absorbed by the polymer network.[10]

The three most commonly used nano-oxides are ZnO, SiO_2, and TiO_2.[11] The silicone framework interacts with additive pigments, changing the material's physical characteristics.[12] Due to its low cohesive energy as a fluid polymer, silicone has poor molecular contact with additive pigments. The formation of larger particles and the accumulation of smaller particles are what modify the hue.[13] According to reports, chemical alterations in polymeric chains or degradation of UV-sensitive pigments are responsible for a prosthesis's changing hue. Exposure to UV radiation induces photodegradation, which significantly alters polymer characteristics, despite occupying very small portion of the visible light spectrum. UV radiation causes considerable degradation in pigments and polymers.[14]

Unwanted color change is a common side effect of weathering, the undesirable reaction of materials to temperature, light exposure, and humidity. Deterioration of polymers reduces the mechanical properties by causing physical and chemical modifications.[15] It has been shown that specimens coated with Zn and Ti nano-oxides provide UV protection at lower concentrations.[16] No color change was observed in specimens with concentrations of 2% and 2.5% of nano-TiO_2. The UV shielding effects of nanosized opacifiers in various ratios have been examined.[17]

The color coordinates of the visible spectrum are described using the Commission Internationale del Eclairage (CIE) Lab color space; in the majority of research studies, an object's spectrum behavior may be seen, the 1964 (10°) observer and D65 illuminant were used to determine the color coordinate readings.[18]

A quick and efficient way to assess the color stability of craniofacial materials is via artificial aging by using water, UV radiation, and temperature. Under identical environmental circumstances, artificial aging is often employed to estimate the polymer lifespan and behavior. Nevertheless, faster artificial aging might affect the degradation process, leading to an inaccurate estimation of polymer lifetime.[19] Few studies explore the impact of nanoparticles (NPs) on the color stability of craniofacial prostheses despite the advancements in NPs and NPs in the industry.

The color stability of a maxillofacial silicone material containing a hybrid nano-oxide material was assessed in the current work. The null hypothesis stated that there would be no variation in color stability among the studied groups.

Materials and Methods

Materials

Tech-sil25 (Technovent Ltd., Bridgend, UK) room-temperature vulcanized with two parts, the base and catalyst, were chosen for the present study to be mixed in a 10:1 ratio with burnt sienna (Technovent Ltd., Bridgend, UK) and cobalt blue (Technovent Ltd., Bridgend, UK) as per the directions given by the manufacturer. Nano-silica (NS) particles (7631-86-9), with a 99.9% purity and a particle size of 30–50 nm, and nano-alumina (NA) (1330–060920), having a 99.9% purity and a particle diameter of 40–60 nm, were chosen as the study's nanofiller materials because of their superior physical and mechanical qualities, large surface areas, tiny particle sizes, and chemical activity. They are also widely available and reasonably priced. Additionally, they are the most commonly used additives in maxillofacial silicone elastic materials and significantly strengthen silicone items.

Mold fabrication

A total of 70 circular disk molds of 2 mm thickness and 20-mm-diameter specimens were designed using AutoCAD 2013. Then, they were processed using the CNC milling machine, which will be used for silicone pouring.[20]

The specimens were fabricated using a vacuum mixer, in which dry earth pigment at 0.2 wt%, part A, part B, and the nanomaterial.[21] Table 1 presents the mixing amount of the base, catalyst, NPs, and pigment for each group in this study, and the following formula was used to calculate the percentage of each item.[20]

$$\text{Total silicone weight} \times \text{concentration of pigment} / 100 = \text{pigment weight} \tag{1}$$

$$\text{Total silicone weight} - \text{pigment weight} = \text{base weight (without NPs)} \tag{2}$$

$$\text{Total silicone weight} - \text{nano powder weight} - \text{pigment weight} = \text{base weight (with NPs)} \quad (3)$$

$$\text{Base weight}/10 = \text{catalyst weight}.20 \quad (4)$$

Using a vacuum mixer, the base was mixed with the nanomaterial at a speed of 360 rpm under a vacuum of -10 bar for 10 min ± 5 s. Then, the colorant was added to the mixture and mixed for 5 min ± 5 s using the vacuum mixer. Then, part B silicone was weighed and added to the mixing bowl. The combination was then mixed in the vacuum mechanical mixer for 5 min ± 5 s.[21]

Table 1: The amount of silicone base (part A) mixed with nano powder and 0.2 wt.% pigments and catalyst (part B) of silicone Tech-Sil 25

Group	Base (g)	Catalyst (g)	Nano-silica (g) (NS)	Nano-alumina (NA) (g)	Pigment (g)
NS 0% NA 0%	99.8	9.98	0	0	0.2
NS 1% NA 0%	98.8	9.88	0	1	0.2
NS 2% NA 0%	97.8	9.78	0	2	0.2
NS 0% NA 1%	98.8	9.88	1	0	0.2
NS 0% NA 2%	97.8	9.78	2	0	0.2
NS 0.5% NA 0.5%	98.8	9.88	0.5	0.5	0.2
NS 1% NA 1%	97.8	9.78	1	1	0.2

A total of 70 samples were fabricated for fourteen groups. Seven groups contained 0.2 wt% burnt sienna, and another seven groups contained 0.2 wt% cobalt blue. The seven groups are control, 1% NA (NA), 2% NA, 1%NS (NS), 2% NS, 0.5% NS+0.5% NA, and 1% NS+1% NA that was added to Tech-sil25. Each group consists of five samples. The grouping of the samples is unclear, shown in Figure 1.

The mixture was injected into the molds and then closed, pressure was applied, and samples were left for 24 h to complete the vulcanization process. The specimens were then removed from the molds, finished, and subjected to artificial weathering for 300 h as shown in Figure 2.

The samples were submitted to initial chromatic analysis before and after 300 h of artificial weathering using a Visible UV reflection spectrophotometer, Model CR30 (China). The color alterations were calculated using the CIE L*a*b* system, established by the "Commission Internationale del' Eclairage - CIE." 21 This system allows the value of ΔE (color variation) between two readings to be calculated by means of the formula:

$$\Delta E = \left[(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2 \right]_{21} \quad (5)$$

where ΔL, Δa, and Δb are the differences in the respective lightness, green–blue, and green–yellow values before and after aging.[21]

The reflectance data were calculated. Three measurements were made, and the values were then averaged. On one side of each specimen, a notch was made to facilitate further investigation. According to Paravina *et al.*,[22] the clinically acceptable limit was 3

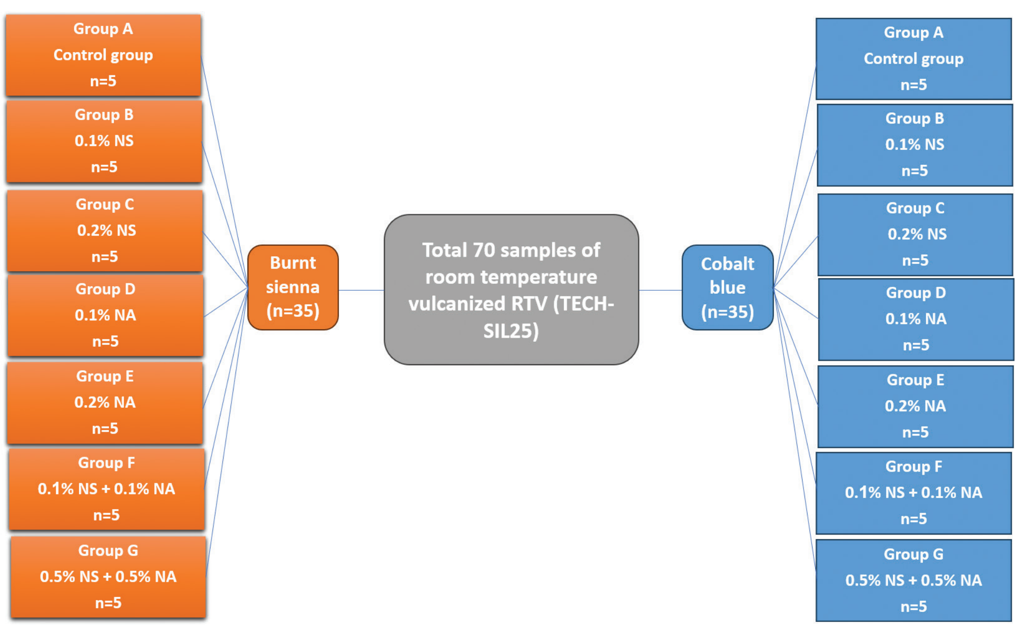

Figure 1: Sample grouping

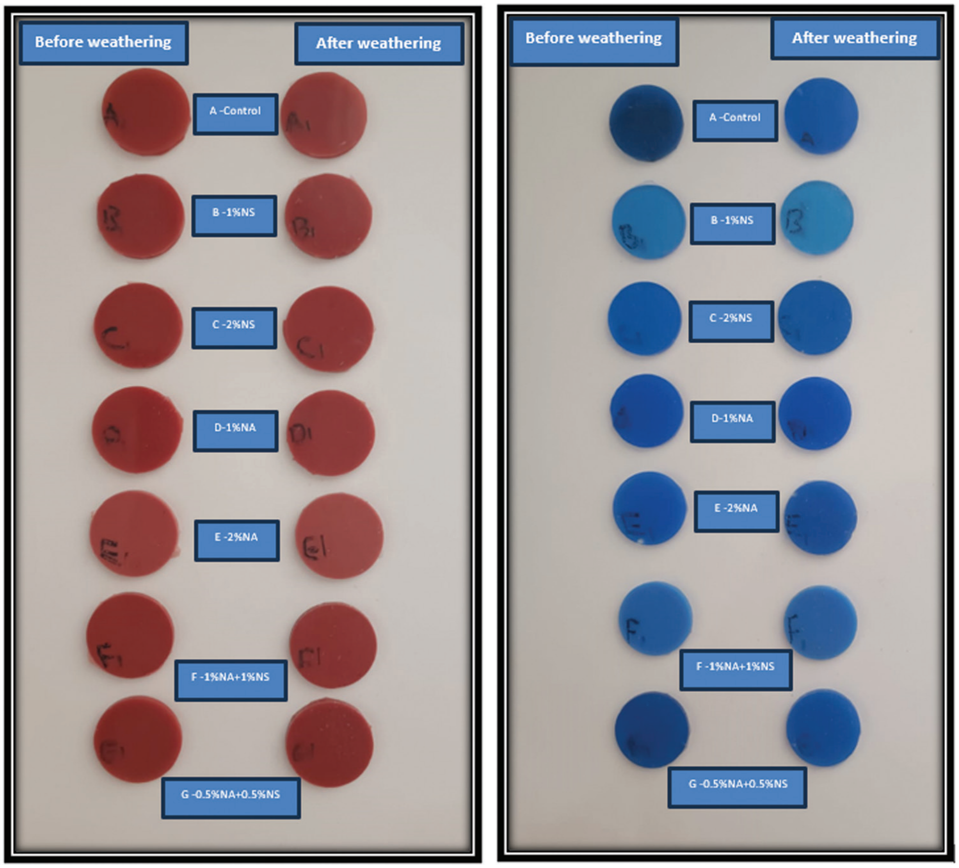

Figure 2: Samples before and after artificial weathering.

units of ΔE^*, and the perceptibility level was 1.1 units of ΔE^*.[23]

One-way analysis of variance (ANOVA) was used for comparing the tested groups' results for color change (ΔE^*) to those of the control group. The Scheffe test was used as a *post hoc* test to determine the distinctions between groups once significant variances were seen, with a level of significance of 0.05 for the color change test. Statistics were deemed significant for $P < 0.05$. The statistical program SPSS (Statistical Package for Social Sciences, version 23.0, SPSS Inc., Chicago, IL, USA) was used to perform all statistical analyses.[24]

Results

The results indicated that the colors changed because of the weathering process. All groups' ΔE^* levels were higher than the detectable limit (1.1 units), but they fell short of the clinically acceptable criterion (3.0 units), and ΔE^* values varied considerably.

Table 2 and Figure 2 show the comparison of the mean and standard deviations for ΔE^* across all groups. There is a highly significant difference between the studied groups for both control and nano-pigmented burnt sienna and cobalt blue groups. The control group and cobalt blue groups with NPs 1%NA, 1%NS, and 1%NS+1%NA samples show substantial color change, while the least noticeable color change was with the 1%NS+1%NA as well as 2%NS and 2%NA pigmented burnt sienna group ($P < 0.05$).

Reduced L*, a*, and b* values were also a result of aging, and there was a significant difference between the groups ($P < 0.05$).

Table 2 and Figure 3 show the descriptive statistical values and one-way ANOVA of the cobalt blue color for both the control group (without NPs addition) and after reinforcement with NPs (NS-NA) group. The color change mean value was higher for the control group than for the nano addition groups.

The mean values of 1% NS+1%NA, 2%NS, and 2%NA were the lowest color change values in the control group. The mean values for 1%NA, 1%NS, and 0.5%NS+0.5%NA were the highest color change values compared to the control group.

Table 3 and Figure 4 show the descriptive statistical value and one-way ANOVA of the burnt sienna color for both the control group (without NPs addition) and after reinforcement with NPs (NS-NA) groups. The color change mean value was higher for the control group than for the nano addition groups.

Table 2: Comparison between both burnt sienna and cobalt blue groups

Studied groups		*N*	Mean	Std. deviation	Std. error	Range Mini.	Range Maxi.	*t* test (P – value)
Control	Cobalt blue	5	4.1516	0.06058	0.02709	4.05	4.20	*P* = 0.003 HS
	Burnt sienna	5	1.3848	0.35755	0.15990	0.75	1.59	
+1%NS	Cobalt blue	5	3.9010	0.01155	0.00517	3.89	3.91	*P* = 0.007 HS
	Burnt sienna	5	1.3116	0.05307	0.02374	1.26	1.39	
+2%NS	Cobalt blue	5	2.1602	0.02827	0.01264	2.11	2.18	*P* = 0.001 HS
	Burnt sienna	5	0.8430	0.02983	0.01334	0.81	0.88	
+1%NA	Cobalt blue	5	3.9500	0.07775	0.03477	3.91	4.09	*P* = 0.002 HS
	Burnt sienna	5	1.4146	0.07703	0.03445	1.30	1.49	
+2%NA	Cobalt blue	5	2.0752	0.02812	0.01258	2.05	2.11	*P* = 0.005 HS
	Burnt sienna	5	0.8210	0.04220	0.01887	0.77	0.88	
1NS+1NA	Cobalt blue	5	0.8032	0.10088	0.04511	0.72	0.97	*P* = 0.009 HS
	Burnt sienna	5	0.6476	0.01791	0.00801	0.63	0.68	
0.5NS+0.5NA	Cobalt blue	5	3.8030	0.07587	0.03393	3.74	3.93	*P* = 0.001 HS
	Burnt sienna	5	1.3144	0.00847	0.00379	1.30	1.32	

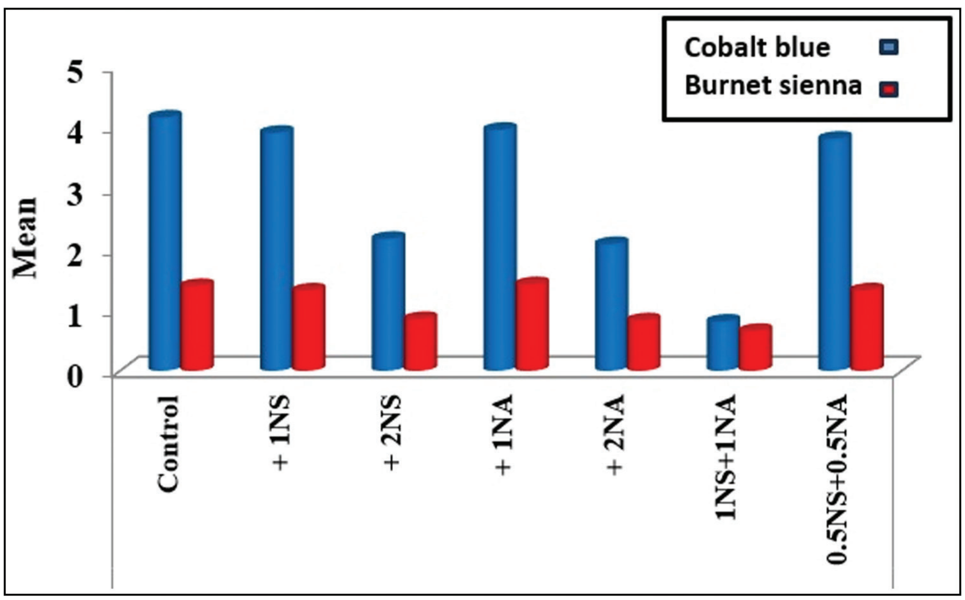

Figure 3: Comparison between both burnt sienna and cobalt blue groups

Table 3 Comparison between control and nano addition groups for cobalt blue pigment

Cobalt blue	*N*	Mean	Std. deviation	Std. error	Range Mini.	Range Maxi.	ANOVA test (P – value)
Control	5	4.15160	0.060583	0.027094	4.047	4.198	*P* = 0.002 HS
+1%NS	5	3.90100	0.011554	0.005167	3.888	3.913	
+2%NS	5	2.16020	0.028270	0.012643	2.111	2.179	
+1%NA	5	3.95000	0.077753	0.034772	3.905	4.086	
+2%NA	5	2.07520	0.028119	0.012575	2.051	2.111	
1%NS+1%NA	5	0.80320	0.100880	0.045115	0.721	0.969	
0.5%NS+0.5%NA	5	3.80300	0.075872	0.033931	3.738	3.931	
Total	35						

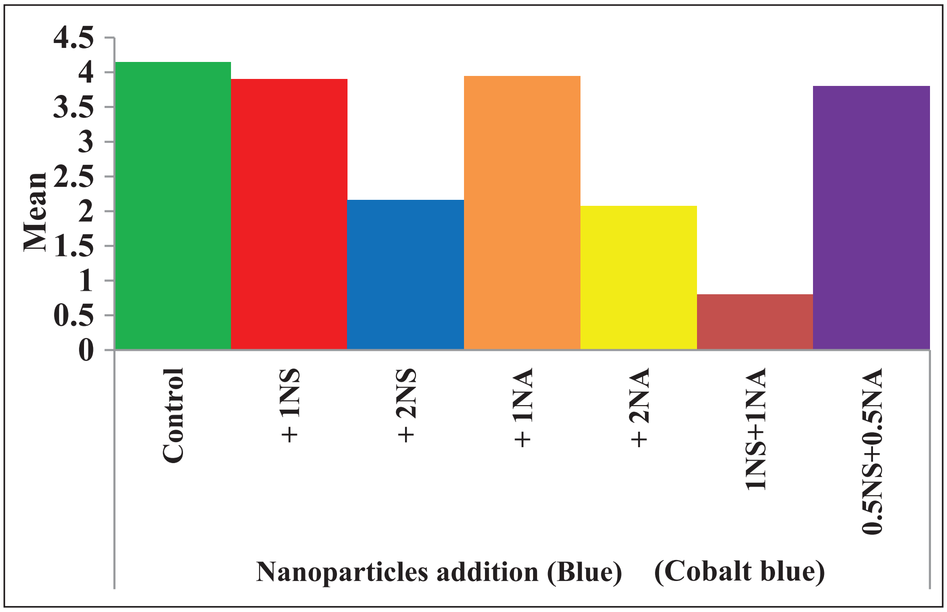

Figure 4: Comparison between studied groups for cobalt blue groups

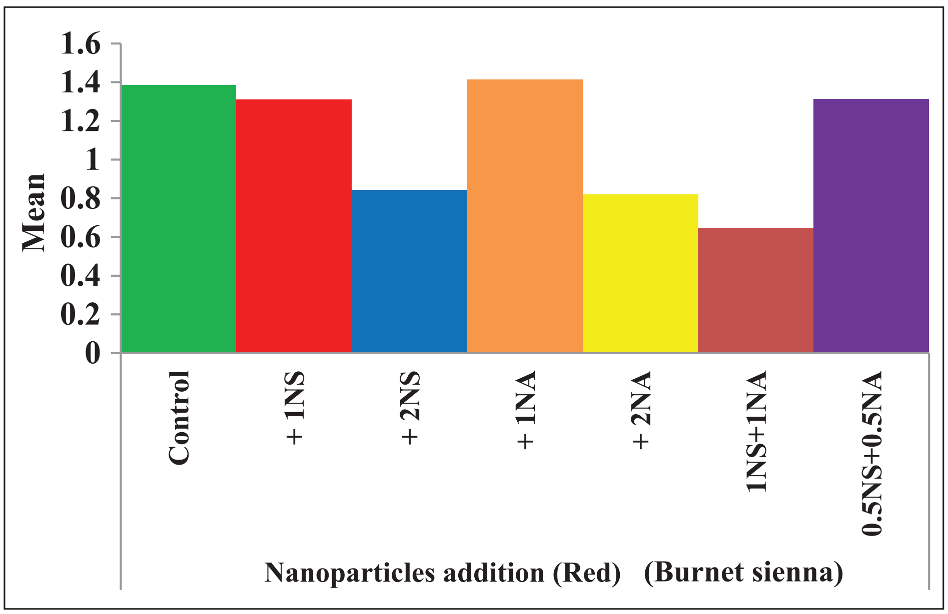

Figure 5: Comparison between studied groups for burnt sienna groups

The mean values of 1% NS+1%NA, 2%NA, and 2%NS were the lowest color change values of the control group. The mean values for 1%NS, 1%NA, and 0.5%NS+0.5%NA were the highest color change values compared to the control group [Figure 5].

Discussion

Color degradation in maxillofacial silicone prosthetics cannot be attributed to a single cause or to age alone. Its incidence is influenced by a number of variables, including environmental exposure, humidity, UV radiation, air pollution, face secretions, and disinfection techniques. Along with these external influences, internal considerations are also quite important. For instance, silicone composition, level of crosslinking, curing technique, and extrinsic and intrinsic stains may all have an impact on silicone prosthetics.[25]

Material color stability is defined as whether materials can or cannot retain their color over time in a certain setting. The American Dental Association advises using the Munsell and CIE L*a*b* color schemes to evaluate chromatic variations and identify color alterations. The maxillofacial prosthesis should ideally be built of materials that exhibit good color stability when exposed to environmental weathering in order to be visually

Table 4: Comparison between control and nano addition groups for burnt sienna pigment

Burnet sienna	N	Mean	Std. Deviation	Std. Error	Range		ANOVA test (P – value)
					Mini.	Maxi.	
Control	5	1.38480	0.357545	0.159899	0.750	1.593	$P = 0.008$ HS
+1%NS	5	1.31160	0.053074	0.023735	1.264	1.392	
+2%NS	5	0.84300	0.029833	0.013342	0.806	0.877	
+1%NA	5	1.31460	0.077028	0.034448	1.303	1.489	
+2%NA	5	0.82100	0.042202	0.018873	0.768	0.877	
1%NS+1%NA	5	0.64760	0.017911	0.008010	0.632	0.678	
0.5%NS+0.5%NA	5	1.31440	0.008473	0.003789	1.301	1.323	
Total	35						

pleasing and functional for a long period before they need to be replaced.[22] Therefore, the present research was conducted to compare how two NPs SiO_2 and Al_2O_3, and their composite can protect the maxillofacial material from color-changing in response to artificial weathering conditions.

This study uses a highly effective composite that is created by mixing NPs with polymeric reinforcement as a matrix in a novel three-phase composite reinforcement by blending two different particles, SiO_2 and Al_2O_3 nano-oxide, in a specific ratio, that has the possibility to enhance the silicone polymers' overall properties and bring realistic maxillofacial prosthesis closer to their optimum features because of their high elasticity modulus and microfiller with excellent flexibility.[26]

Table 2 and Figure 2 show the comparison of the mean and standard deviations for ΔE^* across all groups for both cobalt blue and burnt sienna pigments. There is a highly significant difference between the studied groups for both control and nano-pigmented burnt sienna and cobalt blue groups. The control group shows the highest color change, followed by cobalt blue groups with NPs 1%NA,1%NS, and 0.5%NS+0.5%NA samples showing high color change. It has been observed that artificial aging has negative impacts on silicone's color stability, regardless of the presence of NPs.[3,25] Two different kinds of colorants have been used, burnt sienna and cobalt blue. The differences in the result could be due to the metallic oxide nature of each colorant and the ionic connection between the burnt sienna pigment particles that increase their stability. For cobalt blue pigments, the low color stability may be due to their particle size and refractive indices as inorganic pigments absorb and scatter light, making them more opaque, which have lower refractive indices and, therefore, more transparent.[27]

The 1% nano pigment groups with poor color stability may be caused by small quantities of the material that are affected by photocatalytic activities. According to reports, the aging process causes NP aggregation due to the long-term impacts of photo-oxidative processes.[18] As shown by Gupta *et al.* most color changes result from accelerated aging, and the presence of pigments changes how weathering affects the color. The best color stability was found in inorganic colorants.[28]

Table 3 and Figure 3 show the descriptive statistical value and one-way ANOVA of the cobalt blue color for both the control group (without NPs addition) and after reinforcement with NPs (NS-NA) groups. The color change mean value was higher for the control group than for the nano additive groups. The silicone samples in the current investigation that had no nano additive had a noticeable color change that was likely brought on by artificial aging. This was due to the energy of UV light being absorbed by silicone materials, which causes the polymer chains to break and the generates free radicals.[10]

The mean value for the cobalt blue pigment with 1%NA, 1%NS, and 0.5%NS+0.5%NA was the highest color change value. The existence of pigments acts is mostly responsible for altering the color of maxillofacial prosthetics.[29] In this study, the cobalt blue with 1% nano additive percentage groups exhibited extreme color change and dropped below the suitable clinical threshold (3.0 units). This might be due to the physical and chemical characteristics of the cobalt blue pigment and its response to weathering, which affects its optical properties. The main factor in the degeneration of the color of polymeric substances is a photo-oxidative assault on their chemical composition, which results from the interaction of oxygen and natural light.[27]

Cobalt blue nano-pigmented groups 1%NS+1%NA, 2% NS, and 2%NA showed the lowest color change values compared to the control group. The color of the copolymer might be stabilized by the addition of NPs. Han *et al.* evaluated UV-protecting ability of nano-oxides (TiO_2, ZnO, and CeO_2). The combination of mixed pigments with 2% nano-CeO_2 and 2.5% nano-TiO_2 produced the highest color stability during artificial aging.[17]

Table 4 and Figure 4 show the descriptive statistical value and one-way ANOVA of the burnt sienna color for both the control group (without NPs addition) and after reinforcement with NPs (NS-NA) groups. The color change mean value was higher for the control group than for the nano additive groups.

The mean values for samples with burnt sienna pigment in all groups, including the control group, show good color stability. The control group exhibited the lowest color stability, followed by 0.5%NS+0.5%NA, 1%NA, and 1%NS. The least noticeable color change was observed in the 1%NS+1%NA, as well as 2%NS and 2%NA pigmented burnt sienna group ($P < 0.05$). The least amount of color change was seen (ΔE^* about =1.1) by the visual system as the threshold. This may be due to the NPs (2%) that act as a shield from UV against photo-oxidation, providing more color stability.[30]

The findings of this study agreed with those of Hatamleh and watts that found a high color shift among the pigmented group, which was connected to ongoing chemical polymerization. Different outcomes might be explained by differences in silicone material, color, and aging conditions.[6] Similarly, the current research detected that combining a pigment with NPs might lessen the degree of color shift. In addition, the protection provided by silicone specimens against UV radiation improved with the addition of 2%wt. Artificial aging has been shown to have negative impacts on the color stability of silicone, both with and without NPs. However, the aging process as well as the type of pigment used have an impact on color stability.[15-17,30]

This study was also incompatible with Kiat-amnuay *et al.*, who investigated the color stability of several dry earth colors in maxillofacial silicone and observed that red dry earth pigment was poorly stable in terms of color after being exposed to microwave radiation.[31]

Conclusion

The following conclusions are based on the limitations of the current study. It can be stated that the addition of 2% hybrid NPs can improve the color stability for both the burnt sienna and cobalt blue pigment groups. The variation in color of the burnt sienna group was less than that of the cobalt blue groups. Burnt sienna pigment samples with hybrid nano 1%NS+1%NA showed the highest color stability. The visual system perceives the least color change detectable by the visual system, which is the threshold, while the cobalt blue pigment shows most color change. The color shift was within the acceptable clinical level for all groups. This research demonstrates that the color stability of silicone elastomers might be improved by adding multiple types of fillers with varying characteristics and size scales in the appropriate amounts. The combination of various filler reinforcements holds out a chance of enhancing the anti-aging properties of the maxillofacial silicone elastomer and acting as a shield protecting its color, which will offer a clinical advantage to prolong the shelf life of the facial prosthesis as well as improve the aesthetic quality of a facial prosthesis by maintaining its color.

Data availability

The research data used to support the findings of the current study are available from the corresponding author upon request.

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Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Sinada GG, Al Mardini M, Suzuki M. Maxillofacial prosthodontics. In: Facial Trauma Surgery. Amsterdam, The Netherlands: Elsevier; 2020. p. 458-462.
2. Hatamleh MM, Polyzois GL, Nuseir A, Hatamleh K, Alnassavi A. Mechanical properties and simulated aging of silicone maxillofacial elastomers: Advancements in the past 45 years. J Prosthodont 2016;25:418-26.
3. Cifter ED, Ozdemir-Karatas M, Cinarli A, Sancakli E, Balik A, Evlioglu G. In vitro study of effects of aging and processing conditions of color change in maxillofacial silicone elastomers. BMC Oral Health 2019;19:32.
4. McHutchion L, Zhao L, Dixon S, Seelaus R. Thresholds of perceivable color difference in silicone: A pilot study. Int J Maxillofac Prosthet 2020;3:12-22.
5. Goiato MC, Pesqueria AA, Dos Santos DM, Zavanelli AC, Do Pardo Ribeiru P. Color stability comparison of silicone facial prostheses following disinfection. J Prosthodont 2009;18:242-4.
6. Hatamleh MM, Watts DC. Porosity and color of maxillofacial elastomer. J Prosthodont 2011;20:60-6.
7. Llena C, Lozano E, Amengual J, Forner L. Reliability of two color selection devices in matching and measuring tooth color. J Contemp Dent Pract 2011;12:19-23.
8. Farah A, Sherriff M, Coward T. Color stability of nonpigmented and pigmented maxillofacial silicone elastomer exposed to 3 different environments. J Prosthet Dent 2018;120:476-82.
9. Nguyen CT, Chambers MS, Powers JM, Kiat-Amnuay S. Effect of opacifiers and UV absorbers on pigmented maxillofacial silicone elastomer, part 2: Mechanical properties after artificial aging. J Prosthet Dent 2013;109:402-10.
10. Bangera BS, Guttal SS. Evaluation of varying concentrations of nano-oxides as ultraviolet protective agents when incorporated in maxillofacial silicones: An in vitro study. J Prosthet Dent 2014;112:1567-72.
11. Goiato MC, Haddad MF, Santos DM, Pesqueira AA, Moreno A. Hardness evaluation of prosthetic silicones containing opacifiers following chemical disinfection and accelerated aging. Braz Oral Res 2010;24:303-8.
12. Nobrega AS, Andreotti AM, Moreno A, Sinhoreti MA, dos Santos DM, Goiato MC. Influence of adding nanoparticles on the hardness, tear strength, and permanent deformation of facial silicone subjected to accelerated aging. J Prosthet Dent 2016;116:623-9.e1.
13. Wei L, Lu J, Xu H, Patel A, Chen ZS, Chen G. Silver nanoparticles: Synthesis, properties, and therapeutic applications. Drug Discov Today 2015;20:595-601.
14. Haddad MF, Goiato MC, Dos Santos DM, Moreno A, Pesqueria AA. Color stability of maxillofacial silicone with nanoparticle pigments and opacifiers submitted to disinfection and artificial aging. J Biomed Opt 2011;16:095004.

15. Eltayyar NH, Alshimy AM, Abushelib MN. Evaluation of intrinsic color stability of facial silicone elastomer reinforced with different nanoparticles. Alex Dent J 2016;41:501.
16. Akash RN, Guttal SS. Effect of incorporation of nano-oxides on color stability of maxillofacial silicone elastomer subjected to outdoor weathering. J Prosthodont 2015;24:569-75.
17. Han Y, Zhao Y, Xie C, Powers JM, Kiat-amnuay S. Color stability of pigmented maxillofacial silicone elastomer: Effects of nano-oxides as opacifiers. J Dent 2010;38:e100-5.
18. Kantola R, Lassila LVJ, Tolvanen M, Valittu PK. Color stability of thermochromic pigment in maxillofacial silicone. J Adv Prosthodont 2013;5:75-83.
19. Mehta S, Nandeeshwar D. A spectrophotometric analysis of extraoral aging conditions on the color stability of maxillofacial silicone. J Indian Prosthodont Soc 2017;17:355.
20. Shihab NM. Studying some Mechanical Properties of Maxillofacial Silicone Material before and after Incorporation of Intrinsic Pigments and Artificial aging. M. Sc. Thesis. University of Baghdad; 2018.
21. Bunyan SF, Abood AZ. Color changes in dry pigmented tech-Sil25 maxillofacial elastomer after artificial weathering. Indian J Forensic Med Toxicol 2019;13:1450.
22. Dos Santos D, Goiato M, Sinhoreti M, Fernandez A, Ribeiro P, Carvalho S. Color stability of polymers for facial prosthesis. J Craniofac Surg 2010;21:54-8.
23. Paravina RD, Majkic G, Del Mar Perez M, Kiat-Amnuay S. Color difference thresholds of maxillofacial skin replications. J Prosthodont 2009;18:618-25.
24. Al-Harbi FA, Ayad NM, Saber MA, ArRejaie AS, Morgano SM. Mechanical behavior and color change of facial prosthetic elastomers after outdoor weathering in a hot and humid climate. J Prosthet Dent 2015;113:146-51.
25. Sonnahalli NK, Chowdhary R. Effect of nanoparticles on color stability and mechanical and biological properties of maxillofacial silicone elastomer: A systematic review. TJIPS 2020;20:244.
26. Bunyan SF, Mohamad Suhaimi F, Mohidden Mostafa Zardawi F, Mohd Noor SNF, Zabidi MA. Enhancement of tech-Sil25 maxillofacial silicone mechanical properties after artificial weathering through addition of nanoparticles. Int J Dent 2022;2022:4082168.
27. Lekha K, Kumar HD. The effect of outdoor weathering on color stability of silicone and acrylic resin, pigments-A comparative evaluation: An in vitro study. Int J Prosthodont Endod 2011;5:81-5.
28. Gupta P, Deshpande S, Radke U, Ughade S, Sethuraman R. The color stability of maxillofacial silicones: A systematic review and meta analysis. J Indian Prosthodont Soc 2021;21:138.
29. Chowdhary R. Effect of adding silver nanoparticle on physical and mechanical properties of maxillofacial silicone elastomer material-an in-vitro study. J Prosthodont Res 2020;64:431-5.
30. Nguyen TV, Dao PH, Duong KL, Duong QH, Vu QT, Nguyen AH, *et al*. Effect of R-TiO2 and ZnO nanoparticles on the UV-shielding efficiency of water-borne acrylic coating. Prog Org Coat 2017;110:114-21.
31. Kiat-amnuay S, Beerbower M, Powers JM, Paravina RD. Influence of pigments and opacifiers on color stability of silicone maxillofacial elastomer. J Dent 2009;37:e45-50.