Effect of Organic and Inorganic Nanoparticles on Colour Stability and Mechanical Properties of Heat Vulcanised Maxillofacial Silicone Elastomer: a Comparative Study

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ABSTRACT

Objectives: The purpose of this comparative study *in vitro* was to evaluate the effect of organic and inorganic nanoparticles on colour stability, tear strength and hardness of maxillofacial silicone elastomer at baseline and when subjected to outdoor weathering for 6 months.
Material and Methods: A total of 240 specimens were fabricated using M511 platinum silicone which were divided into total 4 groups (n = 60) based on the type of nanoparticles (control, polytetrafuoroethylene [PTFE], titanium dioxide [TiO_2], zinc oxide [ZnO]) added and each group was further divided into 3 subgroups (n = 20) for colour, tear strength (TS) and hardness (H) testing. The tests were conducted and data was obtained both before and after outdoor weathering of 6 months.
Results: Minimum colour change after weathering was observed in PTFE group (ΔE = 2.23). TiO_2 group showed maximum TS (12.01 N/mm) followed by PTFE group (10.85 N/mm) before weathering. After weathering, maximum TS was shown by TiO_2 group (12.9 N/mm) and PTFE group (12.54 N/mm). TiO_2 group showed maximum hardness (24.15 shore A) before weathering and PTFE group showed maximum hardness (33.43 shore A) after weathering.
Conclusions: Within the limitations of this study, it can be concluded that the addition of polytetrafuoroethylene nanoparticles to the polymer enhances both the optical as well as mechanical properties and can be considered favourable for the extended life of the prosthesis.

Keywords: maxillofacial prosthesis; nanoparticles; polytetrafluoroethylene; silicone elastomer; titanium dioxide; zinc oxide.

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INTRODUCTION

Silicone elastomers are one of the most commonly used maxillofacial materials because of their chemical inertness, biocompatibility, and lightweight. However, the major concern with these materials is their deterioration in a short span of time because of poor colour stability and alteration of mechanical properties such as tear strength and hardness [1-6]. Tear strength is a crucial property in the longevity of function of maxillofacial prosthesis as these prostheses need to be made thin at the margins so that they can easily mask their presence to adjacent facial tissues, and usually get torn at the margins during removal at night or for cleaning [2-3]. The desired hardness of maxillofacial material should be 10 to 45 shore A hardness, as this matches with the adjacent facial skin giving the realistic effect to the prosthesis [3]. The hardness of maxillofacial elastomers usually increases or decreases with time due to photodegradation, which leads to uneven molecular weight distribution. The material becomes hard if there is an increase in cross-linking and hence increased network density. On the other hand, if the chain scission is dominant, the material becomes softer. This change in hardness might render the maxillofacial elastomer noticeable and hence unaesthetic [4].

Apart from these depleting mechanical properties, the deterioration in colour is reported to be one of the commonest reasons for the patient to seek remaking of the prosthesis. Owing to the poor colour stability and durability, the silicone prostheses may need replacement as early as 6 months in some patients. The average life span of silicone prostheses has been reported to be 1.5 years [1].

The incorporation of nano-particles has been recommended to overcome the deterioration of silicone with time. Studies pertaining to the effect of incorporation of various types of inorganic nanoparticles (titanium dioxide [TiO_2], zinc oxide [ZnO], cerium [Ce], silicon dioxide [SiO_2]) have diverse contrasting results which favour one type of nanoparticle over another for improving the anti-aging property [5-14].

The concentration of nanoparticles is very critical in affecting the mechanical properties as well as the colour of maxillofacial silicone elastomers. Because of the high surface energy and chemical reactivity of nano-oxides, these may agglomerate at higher concentrations and act as stress concentrating areas, thereby decreasing the mechanical strength of silicone elastomers. Some studies indicate that the 2% by weight concentration of TiO_2 and ZnO nanoparticles can be utilized to elicit their benefit without the risk of agglomeration [1,15]. It is also observed that the improvement in mechanical properties after adding inorganic nanoparticles is at the cost of undesirable decrease in translucency of the material rendering the prosthesis life less.

Though the incorporation of organic nanoparticles is being used to optimise the properties of industrial silicones, the effect of their addition to maxillofacial silicone elastomer has not been explored. Amongst the organic nanoparticles, Polytetrafluoroethylene (PTFE) has been described as a material with high durability, resistance to attack by chemicals and can withstand extreme temperature conditions. In a study by Park [16], incorporation of 5% micronized PTFE in Methyl silicone elastomers for outdoor applications has been shown to enhance the mechanical properties. However, the silicone tested in this study was not a medical-grade silicone and is used typically for industrial purposes.

Though the risk of agglomeration of inorganic nanoparticles has been pointed out by researchers, so far, no study has been done to investigate the effect of biocompatible organic nanoparticles such as PTFE in maxillofacial silicone elastomer [1,15,17,18].

Available literature lacks conclusive evidence with respect to the type of nanoparticles that would structurally modify the silicone elastomer to provide the best combination of colour stability, tear strength, and hardness. Therefore, the present comparative *in vitro* study was conducted to evaluate the effects of different nanoparticles (organic and inorganic) on both mechanical properties and colour change of maxillofacial silicone elastomer when subjected to outdoor weathering.

Null hypothesis of the study was that the addition of organic and inorganic nanoparticles does not have any effect on mechanical properties and colour stability of maxillofacial silicone elastomer.

MATERIAL AND METHODS

Specimens for evaluation of colour, tear strength, and hardness were made in stainless steel molds designed according to ASTM specifications (www.plantech.com/wp-content/uploads/2017/05/ASTM-D2240-Durometer-Hardness.pdf) using AutoCAD 2013 program (Autodesk Inc.; CA, San Rafael, USA) and processed by computer aided machining (Figure 1). For colour, molds of dimension 10 x 5 x 2 mm were made. Dimensions of the molds for tear strength and hardness were according to ASTM D624 die C and ASTM D2240 respectively.

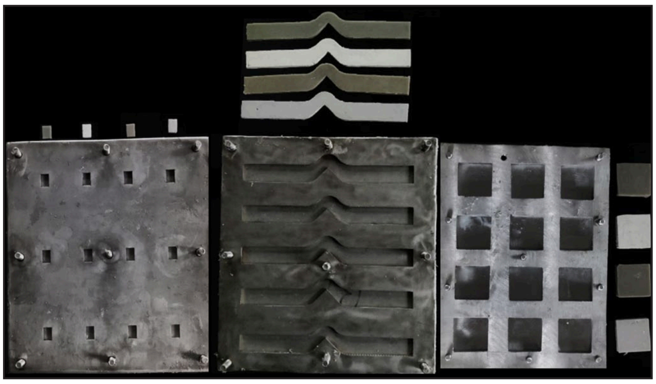

Figure 1. Stainless steel mold for colour specimen, tear strength testing specimen, and harness testing specimen fabrication (left to right) along with specimen of each group.

A total of 240 specimens were assigned to 4 groups (n = 60 each) based on the type of nanoparticles added which were further divided into 3 subgroups based on properties to be tested (Table 1). A two part silicone (M511 Platinum silicone - Technovent Ltd. MaxFac India; Bridgend, Wales, UK) (Table 2) was mixed in the ratio of 10 : 1 (part A : part B), vacuumed, and injected into mold cavity according to manufacturer's instructions. Based on literature, 5% PTFE, 2% TiO_2 and 2% ZnO nanoparticles (Nanoshel LLC - Intelligent Materials Pvt. Ltd.; Wilmington, DE, USA) were used as fillers after weighing using digital scale (Mitutoyo America Co.; Aurora, IL, USA).

Table 1. Groups and subgroups according to the type of nanoparticles incorporated

Serial No.	Group	Subgroup
1	Control	Colour: rectangular shape; hardness: square shape; tear strength: ASTM D624 die C
2	PTFE	
3	Ti	
4	Zn	

PTFE = polytetrafuoroethylene.

Nanoparticles were mixed with part A of silicone initially with metal spatula followed by vacuum mechanical mixer (SIRIO dental S.R.L.; Meldola FC, Italy) at a speed of 150 rpm for 10 min to facilitate even distribution of nanoparticles and prevent its agglomeration. Part B along with yellow, brown and blue intrinsic pigments (Technovent Ltd., MaxFac India) was then added to part A-nanoparticles mixture and mixed under vacuum (SIRIO dental S.R.L.) for 30 min. The mixture was then injected into the molds and closed under 10 MPa pressure for 30 min. Molds then were kept in hot air oven (PID91S - Thermotech Engineering (India) LLP.; Kharabwadi, Maharashtra, India) for 1 h. After 24 h, samples were removed from mold cavities and excess was removed using scissors.

Equipment detail used for testing the properties are listed in Table 3. For colour measurement ultraviolet-visible-near infrared (UV-Vis-NIR) spectrophotometer (3600 UV-Vis-NIR - Shimadzu Co.; Kyoto, Japan) was used at 2 degrees observer's angle and D65 illumination. The baseline was created using Barium sulfate powder. The colour coordinates of specimen in CIE Lab colour space were then calculated. The measurements were repeated three times and data averaged.

Tear strength was measured using universal testing machine (MAS-14 - Asian Test Equipments; Ghaziabad, Uttar Pradesh, India). For tear strength testing, the thickness of specimen was measured at the area of right angle using digital vernier calliper. The specimens were then mounted on universal testing machine and stretched at a constant speed of 500 mm/min until rupture. The maximum force required to rupture was recorded. To calculate the tear strength following equation was used:

$$\text{Tear strength} = \frac{\text{Force (N)}}{\text{Thickness of specimen (mm)}}$$

Table 2. Material for fabrication of specimens

Serial No.	Material	Company
1	M511 Platinum silicone: part A and part B	M511 maxillofacial silicone elastomer (Technovent Ltd., MaxFac India)
2	Intrinsic pigments: P106 yellow colouring agent; P401 brown SS colouring agent; P116 blue colouring agent	M511 maxillofacial silicone elastomer (Technovent Ltd., MaxFac India)
3	Nanoparticles: 35 to 45 nm ZnO; 10 to 25 nm TiO_2; 30 to 40 nm PTFE	Nanoshel LLC - Intelligent Materials Pvt. Ltd.

SS = stainless steel; PTFE = polytetrafuoroethylene.

Table 3. Equipment used for specimen testing

Serial No.	Equipment	Company
1	Vernier calliper	Mitutoyo America Co.; Aurora, IL, USA
2	Universal testing machine	Asian Test Equipments; Ghaziabad, Uttar Pradesh, India
3	Shore A durometer	Precise Instrument Co.; Winchester MA, USA
4	UV-Vis-NIR spectrophotometer	Shimadzu Co.; Kyoto, Japan
5	Scanning electron microscope	Zeiss EVO 18 - Carl Zeiss Microscopy GmbH; Oberkochen, Germany

UV-Vis-NIR = ultraviolet-visible-near infrared.

Hardness was measured using digital shore A durometer (Precise Instrument Co.; Winchester MA, USA). For hardness testing, square specimens of dimension 25 x 25 x 6 mm were prepared. The digital durometer was placed in vertical position and pressor foot was applied parallel to the surface of specimen. Reading was recorded after 1 second of firm contact with the surface of specimens. Five reading were recorded from 1 specimen and average of 5 readings was calculated.

Tests for tear strength and hardness measurements were performed at room temperature (23^o [SD 2^o] C) and relative humidity (50 [SD 10]%) after 36 h at least between vulcanisation and testing as per manufacturer's instructions.

After testing, the specimens were subjected to natural weathering for 6 months, from June 1, 2022 to December 1, 2022. After 6 months of outdoor weathering all the tests were repeated and difference between the readings was calculated. Scanning electron microscopy (SEM) using Zeiss EVO 18 (Carl Zeiss Microscopy GmbH; Oberkochen, Germany) at original magnification x50,000, was used to evaluate the homogeneity of nanoparticles in the specimens.

Statistical analysis

Data of colour and mechanical tests before and after weathering was collected and this parametric data were expressed as mean and standard deviation (M [SD]) of ΔE (difference in colour before and after weathering); tear strength and hardness values before and after weathering. The recorded data of the study was suitably analysed statistically using IBM® SPSS® Statistics version 23.0 software (IBM Corp.; Armonk, New York, USA). The mean for different readings between the groups for hardness and tear strength before and after weathering was compared using the paired t-test where statistical significance was defined at P = 0.005. Analysis of variance (ANOVA) was run to determine any difference between groups for all parameters evaluated. Tukey's post-hoc analysis was applied to find significant differences existing between pairs for ΔE, tear strength, and hardness where $P \leq 0.005$ was considered significant.

RESULTS

Incorporation of different nanoparticles affected the colour change, tear strength and, hardness of maxillofacial silicone elastomer differently both before as well as after weathering.

ANOVA test of means of ΔE of all the groups showed statistically significant difference (P = 0.00) among all groups. Incorporation of PTFE nanoparticles showed minimum ΔE value (2.23) while control group showed maximum ΔE value (4.14). Tukey's post hoc analysis showed insignificant difference in mean of ΔE of PTFE and ZnO group (P = 0.08); and TiO_2 and ZnO group (P = 0.89) (Table 4).

Incorporation of TiO_2 and PTFE nanoparticles significantly (P = 0.00) increased the tear strength of maxillofacial silicone elastomer before weathering. In contrast incorporation of ZnO nanoparticles significantly decreased the tear strength (P = 0.00) (Table 5). ANOVA and Tukey's post hoc analysis of means of groups after weathering showed insignificant difference between control and ZnO (P = 0.78); and TiO_2 and PTFE groups (P = 0.74) (Table 6).

Table 4. Comparative analysis of colour change (ΔE) between groups

Groups	N	Mean (SD)	P-value	Tukey's post hoc pairwise comparison of ΔE	
				Group	Significance[a]
Control	20	4.14 (0.98)	0.00; df = 3	PTFE	0.00
				Ti	0.00
				Zn	0.00
PTFE	20	2.23 (0.69)		Ti	0.01
				Zn	0.89
Ti	20	3.09 (0.95)		Zn	0.08
Zn	20	2.43(0.82)		-	

[a]Significant at the level P < 0.05 (Tuckey's post hoc test).
N = number; SD = standard deviation; PTFE = polytetrafuoroethylene.

Table 5. Comparative assessment of mean values of tear strength of various groups before weathering

Groups	N	Mean (SD)	P-value	Tukey's post hoc pairwise comparison of tear strength	
				Group	Significance[a]
Control	10	9.15 (0.52)	0.00; df = 3	PTFE	0.00
				Ti	0.00
				Zn	0.01
PTFE	10	10.8 (0.8)		Ti	0.00
				Zn	0.00
Ti	10	12.01 (0.61)		Zn	0.00
Zn	10	8.13 (0.84)		-	

[a]Significant at the level $P < 0.05$ (Tuckey's post hoc test).
N = number; SD = standard deviation; PTFE = polytetrafuoroethylene.

Incorporation of TiO_2 and PTFE nanoparticles significantly ($P = 0.00$) increased the hardness of maxillofacial silicone elastomer before weathering whereas incorporation of ZnO nanoparticles decreased the hardness ($P = 0.00$) (Table 7). Pairwise t-tests of means of groups showed significant increase in hardness in all the groups after weathering ($P = 0.00$) (Table 8). ANOVA and Tukey's post hoc analysis of means of groups after weathering showed maximum hardness of PTFE ($P = 0.00$) (Table 8).

SEM image of specimen incorporated with PTFE nanoparticles reveal even distribution of nanoparticles and a fibrillar network in the structure with no agglomeration (Figure 2). SEM image of specimen incorporated with TiO_2 nanoparticles reveal even distribution of nanoparticles with no agglomeration (Figure 3). SEM image of specimen incorporated with ZnO nanoparticles shows agglomeration of nanoparticles with empty areas around the agglomeration (Figure 4).

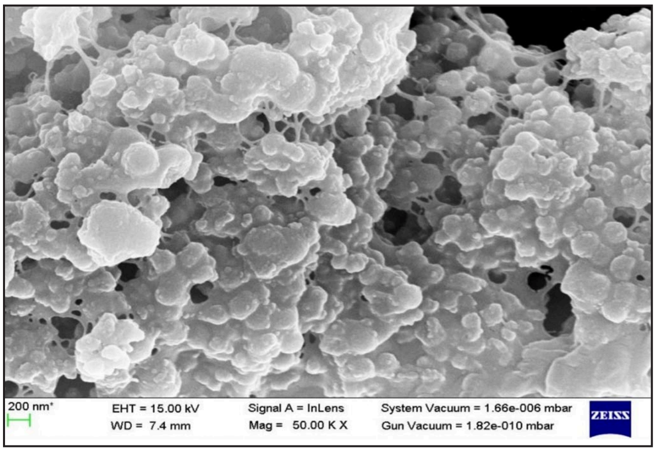

Figure 2. SEM image of specimen incorporated with PTFE nanoparticles (original magnification x50,000).

Table 6. Comparative assessment of mean values of tear strength of various groups after weathering

Groups	N	Mean (SD)	P-value	Tukey's post hoc pairwise comparison of tear strength	
				Group	Significance[a]
Control	10	11.56 (0.88)	0.00; df = 3	PTFE	0.04
				Ti	0.00
				Zn	0.78
PTFE	10	12.54 (0.83)		Ti	0.74
				Zn	0.00
Ti	10	12.90 (0.54)		Zn	0.00
Zn	10	11.22 (0.91)		-	

[a]Significant at the level $P < 0.05$ (Tuckey's post hoc test).
N = number; SD = standard deviation; PTFE = polytetrafuoroethylene.

Table 7. Comparative assessment of mean values of hardness of various groups before weathering

Groups	N	Mean (SD)	P-value	Tukey's post hoc pairwise comparison of hardness	
				Group	Significance[a]
Control	10	21.42 (0.87)	0.00; df = 3	PTFE	0.00
				Ti	0.00
				Zn	0.08
PTFE	10	22.57 (0.81)		Ti	0.01
				Zn	0.00
Ti	10	24.15 (0.88)		Zn	0.00
Zn	10	20.75 (0.98)		-	

[a]Significant at the level $P < 0.05$ (Tuckey's post hoc test).
N = number; SD = standard deviation; PTFE = polytetrafuoroethylene.

Table 8. Comparative assessment of mean values of hardness of various groups after weathering

Groups	N	Mean (SD)	P-value	Tukey's post hoc pairwise comparison of hardness	
				Group	Significance[a]
Control	10	30.45 (0.96)	0.00; df = 3	PTFE	0.00
				Ti	0.00
				Zn	0.00
PTFE	10	33.43 (0.92)		Ti	0.01
				Zn	0.00
Ti	10	32.48 (0.97)		Zn	0.00
Zn	10	28.6 (0.99)		-	

[a]Significant at the level $P < 0.05$ (Tuckey's post hoc test).
N = number; SD = standard deviation; PTFE = polytetrafuoroethylene.

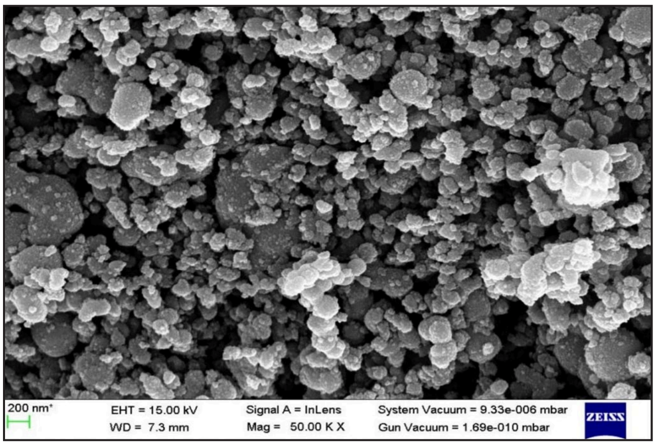

Figure 3. SEM image of specimen incorporated with TiO_2 nanoparticles (original magnification x50,000).

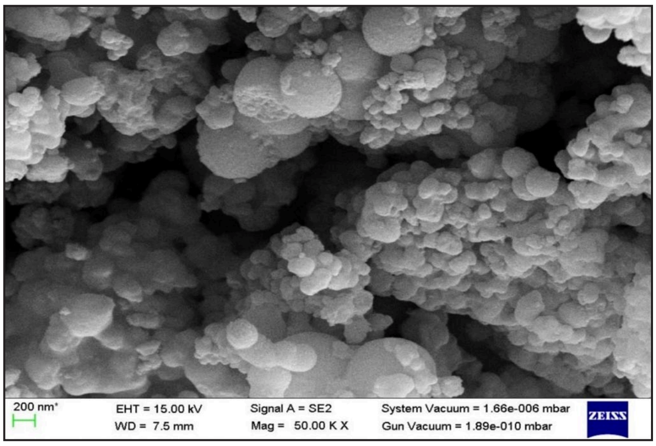

Figure 4. SEM image of specimen incorporated with ZnO nanoparticles (original magnification x50,000).

DISCUSSION

The null hypothesis was rejected in the study as the addition of nanoparticles had significant effect on both colour change as well as mechanical properties at baseline as well as after 6 months of weathering. Incorporation of organic and inorganic nanoparticles improved colour stability as well as mechanical properties except ZnO nanoparticles, incorporation of which decreased the tear strength at baseline as well as after 6 months of outdoor weathering.

One of the commonly used maxillofacial prosthetic material, M511 Platinum silicone, (Technovent Ltd.) was used for the study and manipulated according to the manufacturer's instructions. Yellow, brown, and blue pigments were used as intrinsic colorants as these are the most commonly used to match Indian skin tone. Vacuum mechanical mixer (SIRIO dental S.R.L.) was used to mix all the components to ensure uniform distribution of nanoparticles in the silicone.

After retrieval from the mold the samples were tested for colour and mechanical properties. The samples were then subjected to natural weathering for 6 months. Since the outdoor exposure of the prosthesis in use would be limited to 8 to 12 hours per day, the duration of exposure of 6 months of our study would be equal to 1 year to 1 year 6 months of clinical service [6]. In the present study, weathering was done from June 1, 2022 to December 1, 2022, to ensure the reception of all kinds of weather conditions by the samples. In comparison to accelerated artificial aging, outdoor weathering more closely represents the natural environment and any changes in mechanical properties and colour observed after outdoor weathering would, therefore, reflect the expected mechanical properties and colour changes of the prosthesis in real life situation [16].

Colour fading of maxillofacial prosthesis is the most common reason for dissatisfaction of the patient necessitating remaking. According to many studies, colour change with ΔE values < 1 is not visually perceivable and ΔE values > 3 is not clinically acceptable [7]. Results of our study showed a degradation of colour of all the groups after weathering. Minimum colour change was observed in PTFE group ($\Delta E = 2.23$) followed by ZnO ($\Delta E = 2.43$), TiO_2 ($\Delta E = 3.09$) and maximum colour change was observed in control group ($\Delta E = 4.14$). Hence, the colour change in all groups was clinically acceptable except in control group thereby indicating that incorporation of nanoparticles offers a definitive advantage with respect to colour stability. Because the nanoparticles size is smaller than the UV wavelength, part of the UV light is scattered and partly absorbed by the nanoparticles simultaneously. This imparts UV shielding to the nanoparticle incorporated elastomers. Improvement in colour stability with addition of inorganic nanoparticles in our study is in accordance with results of studies by Akash and Guttal [6], Charoenkijkajorn and Sanohkan [19] PTFE nanoparticles have not been evaluated for colour stability of silicone elastomer in any study. In the present study, the lowest colour change observed in PTFE groups indicates that these nanoparticles are colour protective. Another noteworthy visual observation was that ZnO and TiO_2 incorporated groups did not alter were highly opaque compared to PTFE groups that exhibited the translucency similar to the control group.

Tear strength is one crucial property of maxillofacial silicone elastomers. Results of the study showed statistically significant increase in tear strength of maxillofacial silicone elastomer when reinforced with 2% TiO_2 ($P = 0.000$) and 5% PTFE ($P = 0.000$) whereas statistically significant decrease in tear strength with incorporation of 2% ZnO (P = 0.014) when compared with control group. This increase in tear strength could be due to dissipation of strain energy by the TiO_2 nanoparticles in silicone polymer matrix when tearing is propagated. This results in greater tear resistance and hence greater force to completely break the polymer matrix. The nanoparticles trapped within the silicone matrix form a three dimensional network which increases the density of the silicone and resists the tearing. The increase in tear strength has also been attributed to increase in inter-molecular pressure and adsorption of polymer chain on polymer surface [8,9]. The results obtained for TiO_2 incorporated elastomer are consistent with the studies conducted by Han et al. [5], Abdul Ameer [8], Abdelfattah et al. [10], Shakir and Abdul-Ameer [11], Radey et al. [20].

A significant increase in the tear strength values of PTFE reinforced samples compared to the control group was found. PTFE/polydimethyl siloxane composites are reported to have a layered structure that imparts high tensile strength. The shear developed during mixing the nanoparticles into the elastomer fibrillates the nanoparticles into a continuous network of nodes and fibers. This network structure effectively reinforces the elastomer. Also, when compressive force is applied to the mold, the elastomer is compressed along the thickness direction and expand along the lateral direction and PTFE networks are produced along the silicone flow [16,12]. The PTFE nanoparticles enhance the layered structure along the lateral direction and significantly increase the force required to initiate a tear. These results are in accordance with studies conducted on industrial silicones by Park [16].

After the aging of 6 months, significant increase in tear strength values was seen in all the groups (Control: P = 0.000; PTFE: P = 0.002; TiO_2: P = 0.010; ZnO: P = 0.000). Maximum tear strength of 12.91 and 12.55 N/mm was seen in TiO_2 and PTFE groups with no significant difference between each other (P = 0.749). The control and ZnO group exhibited the tear strength values of 11.56 and 11.22 N/mm with no significant difference from each other (P = 0.783). Maximum increase in tear strength after weathering was seen in ZnO group and control group but even after maximum increase, it did not surpass the tear strength values of TiO_2 and PTFE after weathering. This general trend of increase in tear strength observed after weathering could be attributed to continuous polymerization of silicone during weathering, generation of free radicals that react with each other and further cross-linking within the polymer, formation of bonds between the existing monomers or chains leading to increased density of structure [21-23].

The increase in tear strength values after aging is consistent with the results of some studies of Nobrega et al. [21], Fatalla et al. [22] and Bates et al. [23]; and not in alignment with others [13,14,16,25]. Reason for such contrasting result can be attributed to difference in the silicone elastomer used, fillers used, and the method and duration of aging.

Recommended values of tear strength for maxillofacial silicone elastomer ranges between 5.2 to 17.51 N/mm [3]. Although Tear strength values of all the groups before and after weathering were found to be within this range, TiO_2 and PTFE increased the tear strength significantly relative to the control group, indicating that the addition of these nanoparticles can be beneficial to enhance the longevity of the prosthesis.

The hardness values of TiO_2 and PTFE incorporated groups was found to be significantly higher than that of the control group both before; (TiO_2: P = 0.000; PTFE: P = 0.001) and after weathering (TiO_2 P = 0.000; PTFE: P = 0.000). This result is similar with the results of studies conducted by Abdul-Ameer [8], Abdelfattah et al. [10], Shaqir and Abdul-ameer [11], Park [16], Radey et al. [20], and Mohan et al. [25]. This increase in hardness can be attributed to the structural changes brought by the incorporated nanoparticles in the silicone elastomer such as increased cross-linking density by TiO_2 nanoparticles and formation of nodes and fibres by PTFE nanoparticles [11,16]. The further increase in hardness after weathering of all groups can be attributed to the continued cross linking and loss of plasticizer from the silicone elastomer [22]. Hardness values of all the groups after weathering was within the normal range and hence acceptable clinically.

Amongst the results obtained for various groups in the study, it can be inferred that PTFE and TiO_2 groups showed superior mechanical properties than control group. As regards colour stability, however, PTFE and ZnO groups exhibited better performance, with PTFE group being the most colour stable. The deterioration in mechanical properties in ZnO group can be correlated to the SEM images of the samples, which showed greater empty spaces around the particles thus indicating a tendency of the ZnO nanoparticles to agglomerate at 2% concentration and their incompatibility with the silicone elastomer tested in this study.

Since both mechanical properties and colour stability are vital to the performance of the material in clinical usage, it can be concluded that PTFE provides the best combination of increase in mechanical properties along with colour protection to the silicone elastomer

(M511 Platinum silicone - Technovent Ltd.) with added advantage of unaltered translucency that maintaining the life like appearance of the prosthesis. Addition of PTFE nanoparticles to silicone elastomer can be a promising advancement in pursuit of an ideal maxillofacial prosthetic material.

The study was limited to the evaluation of addition of nanoparticles to one (M511 Platinum silicone - Technovent Ltd.) of the numerous commercially available maxillofacial silicone elastomer and the method of aging was natural outdoor weathering. Though the outdoor weathering of samples for the time duration used in our study is a close simulation of the conditions of service of the prosthesis compared to artificial weathering used in many other studies, it is still not inclusive of some factors that can be linked to the degradative changes during the function of the prosthesis. These include exposure to human body fluids such as sebum and sweat, and the patient's lifestyle factors such as use of cosmetics, swimming in chlorinated water, cleaning solutions etc. The effect of all of these factors can be known only after a nanoparticle incorporated elastomers are put to clinical usage or use of solutions simulating human body fluids *in vitro*.

Also, a myriad of facial prosthetic materials is available today and deterioration of these materials has been recognized as an inherent property of the elastomers, irrespective of the addition of nanoparticles or pigments. Therefore, the results of the studies may vary because of different elastomers tested, nanoparticle characteristics (size, shape and concentration) experimental protocols used, aging conditions and hence, the effect of addition of various nanoparticles to other silicone elastomers needs to be evaluated.

CONCLUSIONS

Based on the findings of the present study, following conclusions were made:

1. Incorporation of organic nanoparticles in silicone improved the colour stability, tear strength and hardness at baseline as well as after 6 months of outdoor weathering.
2. Incorporation of inorganic nanoparticles improved colour stability at baseline as well as after 6 months of outdoor weathering.
3. Incorporation of TiO_2 nanoparticles improved tear strength whereas incorporation of ZnO nanoparticles decreased the tear strength at baseline as well as after 6 months of outdoor weathering.
4. Amongst the 3 nanoparticles evaluated, the addition of polytetrafuoroethylene nanoparticles to the polymer enhances both the optical as well as mechanical properties and can be considered to be the most favourable for the extended life of the prosthesis fabricated from maxillofacial silicone elastomers.

ACKNOWLEDGMENTS AND DISCLOSURE STATEMENTS

The authors report no conflicts of interest related to this study.

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