Review

Effect of nanoparticles on color stability and mechanical and biological properties of maxillofacial silicone elastomer: A systematic review

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Abstract

Aim: The aim of this systematic review was to evaluate the effect of addition of various nanoparticles into maxillofacial silicone elastomer on color stability and mechanical and biological properties of the silicone elastomer.

Settings and Design: This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines(PRISMA).

Materials and Methods: The electronic database search in MEDLINE/PubMed was based on population (silicone elastomer), intervention (nanoparticles), comparison (unreinforced silicone elastomer with nanoparticle-reinforced silicone elastomer), outcome (color stability and mechanical, physical, and biological properties), i.e., PICO framework. The key words used are ("maxillofacial silicone" OR "silicone elastomer" OR "facial silicone") AND ("nanoparticles" OR "Nano-oxides") AND ("colour stability" OR "Hardness," "tensile strength" OR "tear strength" OR "antifungal activity").

Results: The database search resulted in 2099 studies, of which 2066 articles were excluded as they were irrelevant, duplicates, and data were not available. The remaining 33 full-text articles were assessed for eligibility, out of which 2 articles were in Chinese language, 3 articles were thesis documents, and 8 were review articles. A total of 12 articles were excluded and the remaining 20 articles were included. One article was yielded by hand search of references of included studies. A total of 21 studies were included in the present systematic review. \

Conclusion: With the available evidence in the literature, it can be concluded that addition of nanoparticles at various concentrations may improve the physical and mechanical properties and color stability of the prosthesis made from the silicone elastomers.

Keywords: Antifungal activity, color stability, hardness, maxillofacial silicone, nanoparticles, tear strength, tensile strength, ultraviolet protection

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INTRODUCTION

Silicone was introduced in 1960; from then, it has become the most widely used and clinically accepted material for the fabrication of facial prosthesis, because of its ease of manipulation, physical and mechanical properties, and biocompatibility. Silicone material possesses a texture similar to that of human skin; its flexibility provides the patient with both well-being and comfort.[1,2]

However, the silicone material has some limitations. The main problem with the currently used silicone material is its reduced clinical longevity of the prosthesis. Because of its color instability and material deterioration, for example, it exhibits modified texture, poorly fitting edges because of reduced tear strength.[3]

Deteriorating changes occurring in silicone material because of environmental condition can be attributed to photo-oxidative attack that is combined action of oxygen and sunlight on the chemical structure of elastomer.[4] Sunlight is composed of many wavelengths such as infrared light, visible light, and ultraviolet (UV) light.[4] The polymer molecules are more sensitive to UV light, and when exposed, the polymer molecule absorbs photons and leads to photodegradation and the breakup of molecules into smaller pieces. It also results in the change of a molecule's shape, making it irreversible altered.[4]

Various methods have been tried to overcome this polymer deterioration such as addition of pigments and opacifiers, nanoparticles, and nano-oxides.[2-4] Due to the advancement in nanotechnology, the use of nanoparticles in elastomers has been tried to enhance its properties.[4]

Nano-sized particles differ in their physical, chemical, and biological properties compared to their macro-sized counterparts due to their high surface-area-to-volume ratio. Properties of nanoparticles depend on their size and concentration. Based on their concentration, nanoparticles improve the physical, chemical, mechanical, and biological properties of the material in which they are incorporated.[5]

Nanoparticles act as UV shields as the nanoparticles are smaller than the UV light wavelength, and their electrons vibrate when they hit by such radiation, thereby dissipating one portion of the light when absorbing another. Thus, the smaller the nanoparticles, the better the shielding against solar radiation.[6]

Nano-sized zinc oxide (ZnO), titanium dioxide (TiO_2), and cerium oxide (CeO_2) are mainly used as UV shields as they have a high UV absorbing and scattering effect. Nano-sized silicone dioxide (SiO_2), TiO_2, and ZnO are characterized by their small size, large specific area, active function, and strong interfacial interaction with the organic polymer. Therefore, they can improve the physical properties and optical properties of the organic polymer, as well as provide resistance to environmental stress-caused aging.[7]

Several nanoparticles have been tested and studies have confirmed the effectiveness of nanoparticles in improving the color stability by blocking the UV rays and also in improving the color stability, hardness, tear strength, tensile strength, percentage elongation, UV protection, and antifungal properties of silicone elastomer. The aim of the present study is to compare and assess the available evidence through a systematic review of the literature, seeking to answer the following research question: Does incorporation of nanoparticles into the maxillofacial silicone improve the color stability and other physical, mechanical, and biological properties of the silicone elastomer?

MATERIALS AND METHODS

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[8] Before the start of the review, a review methodology was established based on the recommendations of the Cochrane Handbook for Systematic Reviews of Interventions.[9]

Focused question

The focused question was, does incorporation of nanoparticles into maxillofacial silicone elastomer improve the color stability and other physical, mechanical, and biological properties of the elastomer?

Outcome measures

The primary outcome variable measured was the effect of adding nanoparticles into silicone elastomer on color stability, hardness, tear strength, and tensile strength of the silicone elastomer. The secondary outcome variable was effect of adding nanoparticle on biological properties of the silicone elastomer.

Search strategy

A comprehensive bibliographic search was conducted in MEDLINE/PubMed to collect relevant articles published till December 2018 with no limitation on the language and year of publication. A PRISMA statement guideline with predetermined search strategy was used. Furthermore, hand search was performed in the reference sections of studies included (cross-referencing). The search strategies were based on population (silicone elastomer), intervention (nanoparticles), comparison (unreinforced silicone elastomer with nanoparticle-reinforced silicone elastomer), outcome (color stability and mechanical, physical, and biological properties), and a study design, i.e., PICOS framework [Table 1]. The following search terms were used for each property for literature search. Colour stability-(((((((“nanoparticles” AND “nano oxides”) AND “silicone elastomer”) OR “maxillofacial silicone”) OR “maxillofacial silicone elastomer”) AND “colour stability”). Hardness-(((((((“nanoparticles” AND “nano oxides”) AND “silicone elastomer”) OR “maxillofacial silicone”) OR “maxillofacial silicone elastomer”) AND “hardness”). Tear strength-(((((((“nanoparticles” AND “nano oxides”) AND “silicone elastomer”) OR “maxillofacial silicone”) OR “maxillofacial silicone elastomer”) AND “tear strength”). Tensile strength-(((((((“nanoparticles” AND “nano oxides”) AND “silicone elastomer”) OR “maxillofacial silicone”) OR “maxillofacial silicone elastomer”) AND “tensile strength”. Antifungal activity-(((((((“nanoparticles” AND “nano oxides”) AND “silicone elastomer”) OR “maxillofacial silicone”) OR “maxillofacial silicone elastomer” [All Fields]) AND “antifungal activity;” all fields in each search terms were considered. Further, references of all the included studies were screened.

Selection criteria

This review included the *in vitro* studies that are incorporated nanoparticles, nanofillers, or nano-oxides into maxillofacial silicone elastomer and compared the color stability and other physical, mechanical, and biological properties with plain maxillofacial silicone elastomer.

Inclusion criteria

The inclusion criteria for selection of studies were (1) *in vitro* studies involving incorporation of nanoparticles into silicone elastomer; (2) comparison of nanoparticle-incorporated silicone elastomer with a plain silicone elastomer; (3) minimum sample size of 5 for each group; and (4) studies evaluating effect of incorporating nanoparticles on color stability, hardness, tear strength, tensile strength, percentage elongation, UV protection, and antifungal activity of silicone elastomer.

Table 1: PICOS search strategy

PICOS
P: Participants: Silicone elastomer
I: Intervention: Nanoparticles
C: Comparison: Unreinforced silicone elastomer with nanoparticle-reinforced silicone elastomer
O: Outcome: Color stability and mechanical, physical, and biological properties
S: Study design: Systematic review

PICOS: Population, Intervention, Comparison, Outcome, Study design

Exclusion criteria

The exclusion criteria included the articles which investigated the color stability and other physical, mechanical, and biological properties of silicone elastomer incorporated with other filler, coloring agents, pigments, and comparison between the different commercially available brands of maxillofacial silicone material.

Screening and selection

Two authors (NSK and RC) performed the search and screening process (κ =0.83, which indicated near perfect agreement between the two authors). At first, titles and abstracts were analyzed and then the full-text articles were selected and analyzed with careful and through reading based on the inclusion and exclusion criteria for future data extraction. Any disagreements between the authors with the selection or rejection of studies were resolved carefully through discussion.

Data extraction

Data extraction procedure was carried out by the first author and then redefined by the second author. Data extraction was done independently from each full-text articles met inclusion criteria; it was done in standardized form in electronic format (Office Excel 2013 software, Microsoft Corporation.). Information was classified under author/year, type of study, type of nanoparticle used, dimensions of the sample, type of exposure, sample size, properties tested, test methods, silicone material used, and author conclusion.

Assessment of risk of bias and quality

For quality assessment, the following variables were analyzed according to the CRIS guidelines (Checklist for Reporting *in vitro* Studies)[10] for *in vitro* studies: (1) sample preparation and handling; (2) allocation sequence and randomization process; (3) whether the evaluators were blinded; and (4) statistical analysis. Studies with information about all variables were deemed to be of good quality; if 2–3 variables were present, they were deemed of fair quality; and finally, they were classified as being of poor quality when none or just one aspect was covered.

RESULTS

Search and selection

Selection criteria were based on PRISMA statement flowchart [Figure 1]. The database search (P) resulted in 2099 studies, of which 2066 articles were excluded as they were irrelevant, duplicates, and data were not available. The remaining 33 full-text articles were assessed for eligibility, of which 2 articles were in Chinese language, 3 articles were thesis documents, and 8 were review articles. A total of 12 articles were excluded and the remaining 20 articles which were included. One article was yielded by hand search of references of included studies. A total of 21 studies were included in the present systematic review [Figure 1].

Study characteristics

Out of these 21 articles, 5 articles studied the color stability, 13 articles studied the mechanical properties, 1 article studied both color stability and mechanical properties, 1 article studied UV protection, 1 article studied cytotoxicity, and 1 article studied the antifungal activity and biocompatibility.

In a total of 21 articles included, 14 studies have used titanium(Ti), zinc (Zn) based nanoparticles. 2 studies have used cerium (Ce) nanoparticles along with Ti and Zn. Ceramic powder and Barium sulfate (BaSO4) was compared in one study. BaSO4 is tested along with Ti and Zn in 1 study. 2 studies have used Ti fumed silica and silaned silica. 1 study used silver nanoparticles and tested for antifungal and biocompatibility. One study used surface-treated nano-SiO_2. One study used aluminum trioxide (Al_2O_3) with TiO_2. One study used polyhedral silsesquioxane (POSS).

Assessment of risk of bias and quality

Risk of bias and quality assessment of *in vitro* studies were conducted using CRIS guidelines [Table 2], and all the studies showed fair risk of bias.

DISCUSSION

The overall results obtained from this systematic review showed that addition of nanoparticles improved the color stability and mechanical and biological properties

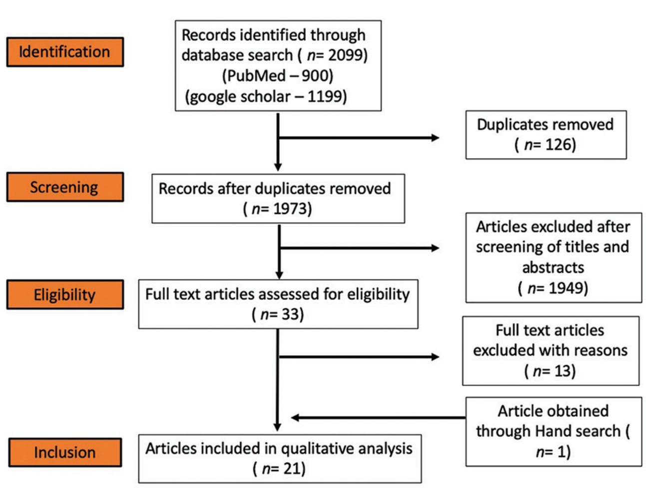

Figure 1: Preferred Reporting Items for Systematic Reviews flowchart

of silicone elastomers. In general, nano-sized particles differ in their physical, chemical, and biological properties compared to their macro-sized counterparts due to their high surface-area-to-volume ratio. Properties of nanoparticles depend on their size and concentration.[5] The environmental condition to which material exposes has an impact on amount of crosslinking, significantly affecting the physical and mechanical properties of the material.[4] Various nanoparticles such as Ti, Zn, Ce, $BaSO_4$, POSS, ceramic powder, and silica have evaluated for their effect on mechanical properties [Table 3].[2-4,11-23]

Mechanical properties

Hardness

The texture of silicone should match with that of the skin of that particular anatomic area to be restored, wherein the texture depends on the hardness of the material.[12,14] The skin covering the orbital, nasal, and ear areas of the maxilla is thin and very close to the bone and cartilage.[12,14] Thus, in order to mimic the texture of these sites, the silicone should exhibit hardness values between 25 and 35 Shore A.[14] Incorporation of nano-sized oxides of Ti, Zn, or Ce at the concentrations of 2.0%, 2.5%, and 3% by weight, respectively, into a silicone-based elastomer increased the hardness of the material.[8] This could be due to dispersion of nanoparticles in the silicone elastomer, which increases the crosslink density, thereby leading to increased hardness, or could be that the nanoparticles affect the elastic modulus of the silicone elastomer.[12] The modulus of elasticity of silicone elastomer is proportional to the Shore A hardness, tear strength, tensile strength, and elongation.[12] However, these increases in hardness values were well within the specification limits of 25–35 Shore A, but most of the commercially available maxillofacial silicone elastomers have hardness values between 25 and 35 Shore A, which is sufficient to maintain the texture similar to that of the skin. Hence, addition of nanoparticles may not enhance the hardness properties of the silicone materials.

Tear strength, tensile strength, and percentage elongation

The tear strength of silicone elastomer is clinically very important as the margins surrounding the facial prosthesis are thin and are usually glued with the help of medical adhesives and are highly susceptibility to tear. The muscle actions during chewing, talking, and laughing cause the remodeling of facial structures such as eyes, mouth, and nose. Thus, the ideal facial prostheses should have a certain degree of flexibility, which can not only avoid the damage of facial prostheses but also give the facial prostheses a more natural appearance.[12] Addition of nano-sized oxides of Ti, Zn, or Ce at the concentrations of 2.0%–2.5% by

Table 2: Assessment of the risk of bias and quality for *in-vitro* studies (Checklist for Reporting *in vitro* Studies guidelines)

Study	Sample preparation and handling	Allocation sequence and randomization process	Blinding	Statistical analysis	Risk of bias
Kiat-amnuay *et al*. (2006)	Yes	No	No	Yes	Fair
Han *et al*. (2008)	Yes	No	No	Yes	Fair
Mohammed *et al*. (2010)	Yes	No	No	Yes	Fair
Mouzakis *et al*. (2010)	Yes	No	No	Yes	Fair
Han *et al*. (2010)	Yes	No	No	Yes	Fair
Haddad *et al*. (2011)	Yes	No	No	Yes	Fair
Pesqueira *et al*. (2012)	Yes	No	No	Yes	Fair
Bangera and Guttal (2014)	Yes	No	No	Yes	Fair
Zayed *et al*. (2014)	Yes	No	No	Yes	Fair
Wang *et al*. (2014)	Yes	No	No	Yes	Fair
Akash and Guttal (2015)	Yes	No	No	Yes	Fair
Nobrega *et al*. (2016)	Yes	No	No	Yes	Fair
Eltayyar NH *et al*. (2016)	Yes	No	No	Yes	Fair
Cevik and Erasla (2017)	Yes	No	No	Yes	Fair
Tukmuchi *et al*. (2017)	Yes	No	No	Yes	Fair
Cevik (2018)	Yes	No	No	Yes	Fair
Azeez *et al*. (2018)	Yes	No	No	Yes	Fair
Shakir DA *et al*. (2018)	Yes	No	No	Yes	Fair
Bishal AK *et al*. (2018)	Yes	No	No	Yes	Fair
Akay *et al*. (2016)	Yes	No	No	Yes	Fair
Meran *et al*. (2018)	Yes	No	No	Yes	Fair

weight increases the tear strength, tensile strength, and percentage elongation. Among the nanoparticles used, the nano-TiO_2 efficiently improves the mechanical properties due to their high specific surface area of nano-TiO_2, which is likely to reinforce the contact area and the extent of binding.[12] However, at a concentration of more than 3%, the same nanoparticles decreased the tear strength, tensile strength, and elongation.[8] This may be due to the fact that nanoparticles at higher concentration exhibit a certain degree of agglomeration because of their high surface energy and high chemical reactivity, which causes the molecular chains to get fixed more firmly around the nanoparticles, weakening the interaction with the silicone elastomer.[12] The agglomeration of nanoparticles, resulting in poor interfacial bonding, which might force cracks not only along the cutting, but also down into the micro-defects of the nanofiller/elastomer matrix.[14] Usually, nanoparticles can bond to polysiloxane. Thus, when the amount of nanoparticles increases, there may be an inadequate amount of polysiloxane to link the nanoparticles effectively, which would lead to a decrease in the interfacial bonding in the nanoparticle silicone elastomer material.[10,20] The most commonly used silicone elastomers have low tear strength and tensile strength which makes edges of the prosthesis susceptible to tear easily. The addition of nanoparticles improves the tear strength, tensile strength, and percentage elongation, thereby increasing the longevity of the prosthesis. For effectively using nanoparticles in improving these mechanical properties of elastomer, these materials need to overcome the agglomeration of nanoparticles. It can be achieved by surface treatment of nanoparticles to reduce its clumping and improve its dispersion into the silicone matrix.[14] Zayed *et al.* employed this surface-treated SiO_2 nanoparticles and showed improvement in its distribution within the silicone matrix and prevented its agglomeration, thereby improving the overall mechanical properties especially in terms of tear strength.[2,24] Therefore, the future research should concentrate on surface treating the other potential nanoparticles such as Ti, Zn, and Ce to improve the tear strength, tensile strength, and percentage elongation.

Color stability

As mentioned earlier, silicone prosthesis often needs to be refabricated, mainly due to color instability. The deteriorating changes occurring in prosthesis made with silicone material are because of environmental condition, when they are exposed, and which can be attributed to photo-oxidative attack, which is a combined action of oxygen and sunlight on the chemical structure of elastomer.[6] Sunlight is composed of many wavelengths such as infrared light, visible light, and UV light.[6] The polymer molecules are more sensitive to UV light. When exposed, these polymer molecules absorb photons and lead to photodegradation, and thus breakup of molecules into smaller pieces. It also results in the change of a molecular shape making it irreversibly altered.[4]

Studies have shown that addition of nano-oxides to a silicone elastomer could improve its color stability [Table 4].[3,6,7,20,24,25] Han *et al.* reported addition of 1% nano-CeO_2 and 2% and 2.5% nano-TiO_2 by weight to the silicone along with pigments exhibited the

Table 3: Effect of nanoparticles on mechanical properties of silicone elastomer

Author and years	Type of nanoparticles	Dimensions of samples	Exposure	Sample size	Properties tested	Test methods	Silicone elastomer used	Results
Han *et al*., 2008	Ti, Zn, Ce	ASTM D412 ASTM D624	-	5	H, TS, TRS, PE	Shore A durometer, universal testing machine, autographic extensometer	A2186	Ti, Zn, or Ce nano-oxides at concentrations of 2.0% and 2.5% improved the overall mechanical properties of the silicone A-2186 maxillofacial elastomer
Mohammed *et al*., 2010	POSS	ASTM D412 ASTM D624	-	6	TS, TRS	Universal testing machine	Factor II	POSS loading into silicone elastomer increased the extension at failure at increased concentration of POSS (5%)
Mouzakis *et al*., 2010	ZnO	Cylindrical plastic molds (internal diameter=27.9 mm and height=5.8 mm)	Dark chamber, outdoor weathering, UV-C, and fluorescence radiation	12	E', E'', tan δ	Dynamic mechanical analyzer	EPISIL-E	There was no influence of ZnO additive concentrations on the dynamic mechanical properties (E' and E'') of the maxillofacial silicone material tested. Sunlight and fluorescence aging procedures induced a reduction of storage and loss modulus, whereas UV-C radiation caused a continuous increase of the same parameters by increasing the ZnO additive concentrations
Pesqueira *et al*., 2012	Ceramic powder	A cylindrical metallic matrix, 30.0 mm in diameter and 6.0 mm in height, (ISO specification 4823:2000)	Disinfection with effervescent tablets, artificial aging chamber	20	DS, DR	DS- Digital scanner by measuring distance between two lines, DR- stereomicroscope with low-angle illumination and at 13×magnification	Silastic MDX 4-4210	Chemical disinfection and also accelerated ageing affected the dimensional stability of the facial silicone with statistically significant results. The silicone's detail reproduction was not affected by these two factors regardless of nanoparticle type, disinfection and accelerated ageing
Bangera and Guttal, 2014	Ti, Zn	20 mm diameter × 2 mm thick	Subjected ultraviolet radiation with ultraviolet A (>315-400 nm) and ultraviolet B (>280-315 nm)	10	UV protection	Ultraviolet spectrophotometer	Cosmesil M511	Compared with Ti nano-oxides (2%-2.5%), Zn nano-oxides in lesser concentrations provided more significant and consistent ultraviolet protection in Cosmesil M511 elastomer.
Zayed *et al*., 2014	Surface-treated SiO_2	ASTM D412 ASTM D624 ASTM D2240	-	21	TS, TRS, PE, H	Universal testing machine, Shore A durometer	A-2186	Surface-treated SiO_2 nanoparticles at a concentration of 3% enhanced the overall mechanical properties of A-2186 silicone elastomer
Wang *et al*., 2014	TiO_2	ASTM D412 ASTM D624 ASTM D2240	Artificial ageing	9	TS, TRS, H	ISO 37:2005 standard on a servo control computerized tensile testing machine ISO 34-1:2004 standard using a servo control computerized tensile testing machine at a crosshead speed of 500 mm/min Shore A durometer based on the ISO 7619-2008 standard	MDX4-4210	Silicone elastomer filled with 2% (w/w) TiO2 nanoparticles results in a material with improved physical properties for the maxillofacial prostheses. However, the elongation at break and the tear strength of the 6% (w/w) composite were significantly compromised

Contd...

Table 3: Contd...

Author and years	Type of nanoparticles	Dimensions of samples	Exposure	Sample size	Properties tested	Test methods	Silicone elastomer used	Results
Nobrega *et al*., 2016	ZnO, $BaSO_4$, and TiO_2	Circular with 30 mm × 2 mm in interior, ASTM D1983-67	Artificial ageing	10	H, TRS	Shore A durometer Universal testing machine (speed of 25 mm/min and load of 166.7N)	Silastic MDX4-4210	TiO_2 nanoparticle addition exhibited hardness values lower than the clinically acceptable range, and $BaSO_4$ nanoparticles had the greatest difficulty dispersing in the silicone matrix. Therefore, the use of ZnO nanoparticles may be a viable method, as they do not negatively affect the material properties evaluated in this study
Cevik and Erasla, 2017	TiO_2, fumed silica, and silaned silica	ASTM D412, ISO 34-1, ASTM D2240-68.	-	5	TS, TRS, PE, H	Gibitre Tensor tensile testing machine, Shore A Durometer.	A-2000 and A-2006	The hydrophobic silica group had significantly higher tensile strength than TiO2 for A-2000. The fumed hydrophilic silica group had significantly higher tensile strength than TiO_2 for A-2006. Most of silica specimens had higher tensile strength when compared with the control and TiO_2 groups for A-2000 and A-2006 silicones. The TiO_2 group had the highest hardness value for A-2000 while the lowest hardness value for A-2006 ($P<0.05$). There was no significant difference of tear strength among the type of additives ($P>0.05$) for A-2000.
Mustafa S *et al*., 2017	SiO_2	ISO 34-1 ISO 37 ISO 7691	-	40	TRS, TS, PE H	Universal testing machine, Shore A Durometer	Cosmesil M-511	All nano-SiO2 group showed a highly significant increase in tear strength, tensile strength, elongation at break and hardness compared to the control group
Cevik 2018	Silaned silica, fumed silica TiO_2	ASTM D2240-68	Dark storage at room temperature for 2 years	16	H	Shore A Durometer	A-2000 and A-2006	Both silicone elastomers, with or without nanoparticles, showed clinically acceptable Shore A hardness values even after dark storage. Nanoparticle addition did not prevent silicone elastomers from hardening effects of time and, finally, A 2000 silicone revealed maximum hardness values in all study groups
Azeez *et al*., 2018	Silver-zinc zeolite	ISO 43-1, ISO 37, ISO 7619-1	-	10	TRS, TS H	Universal testing machine, Shore A Durometer.	VST-50	Silver-zinc zeolite at 1% concentration increased the tear and tensile strength, no effect on hardness, increase in roughness and a decreased the percentage elongation
Shakir DA *et al*., 2018	TiO_2	ASTM D624, ISO 37, ASTM D2240	-	10	TRS, TS, H	Universal testing machine, Shore A Durometer.	VST 50 Cosmesil M511	Nano-TiO_2 increased the TRS, TS and H

TS: Tensile strength, TRS: Tear strength, PE: Percentage elongation, H: Hardness, POSS: Polyhedral silsesquioxanes, E′: Storage modulus, E′′: Loss modulus, tanδ: Damping capacity, DS: Dimensional stability, DR: Detail reproduction, TiO_2; Titanium dioxide, ZnO: Zinc oxide, $BaSO_4$: Barium sulfate, SiO_2: Silicone dioxide, CeO_2: Cerium dioxide

Table 4: Effect of nanoparticles on color stability of silicone elastomer

Author and years	Type of Nanoparticles	Dimensions of samples	Exposure	Sample size	Properties tested	Test methods	Silicone elastomer used	Results
Kiat-amnuay *et al*., 2006	Cd seleno-sulfide coprecipitated with Ba sulfate, natural hydrated iron oxide, synthetic hydrated iron oxide, calcined natural iron oxide, Titanium oxide	22 mm in diameter × 2 mm thick	Artificial ageing	5	CS	Spectrophotometer	MDX4-4210/ type A	At all 3 concentrations, oil pigments mixed with opacifiers helped protect the MDX4-4210/type A silicone elastomer from color degradation over time. Dry pigment Ti white remained the most color stable over time, followed by the pigments mixed with kaolin powder calcined, Georgia kaolin, Artskin white, and Ti white artists' oil color
Han *et al*., 2010	TiO_2, ZnO, CeO_2	22 mm in diameter × 2 mm thick	-	5	CS	Spectrophotometer	A2186	1% nano-CeO_2, 2% and 2.5% nanoTiO_2 wen used as opacifiers exhibited the least color changes
Haddad *et al*., 2011	ceramic powder, $BaSO_4$	-	Disinfection and artificial ageing	10	CS	Spectrophotometer	MDX4-4210	The association between pigment and $BaSO_4$ opacifier (GIV) was more stable in relationship to color change (E)
Akash and Guttal., 2015	Ti, Zn	20 mm in diameter × 2 mm thick	Outdoor weathering for 6 months	30	CS	Spectrophotometer	Cosmesil M511	ZnO-incorporated Cosmesil M511 specimens showed minimal or no color change and proved to be most color stable after being subjected to outdoor weathering
Eltayyar NH *et al*., 2016	TiO_2, $Al2O_3$	10 mm diameter × 3 mm thick	Sunlight, ultraviolet light, simulate sweat	21	CS	spectrophotometer	MDX 4-4210	All groups exhibited great color change regardless artificial aging conditions TiO_2 group was more stable than Al_2O_3 after 30 days regarding ultraviolet light. Al_2O_3 group was more stable than TiO_2 after 30 days regarding sunlight and sweat
Mustafa S *et al*., 2017	SiO_2	ASTM D1535-13	-	40	CS	Spectrophotometer, Munsell visual color measurement test.	Cosmesil M-511	Spectrophotometer results showed a highly significant decrease in translucency of the material with all nanofiller concentrations
Bishal AK *et al*., 2018	TiO_2 nanofilm	5 mm diameter × 2 mm thickness	Artificial ageing	20	CS	Spectroradiometer and 1 illuminator	A - 2000	TiO_2 nanocoting effectively reduced the color degradation of the silicone elastomer

CS: Color stability, TiO_2: Titanium dioxide, ZnO: Zinc oxide, $BaSO_4$: Barium sulfate, SiO_2: Silicone dioxide, CeO_2: Cerium dioxide, Cd: Cadmium

Table 5: Effect of nanoparticles on biological properties of silicone elastomer

Author and years	Type of nanoparticles	Dimensions of samples	Exposure	Sample size	Properties	Test conditions	Silicone elastomer used	Results
Akay *et al.*, 2016	TiO_2, fumed silica, and silaned silica	2 mm height × 10 mm diameter	Autoclaved	18	Cytotoxicity	MTT assay	A - 2000, A - 2006	Nanoparticles of TiO_2, fumed silica, and silaned silica added to a commercial silicone-based elastomer used for fabrication of maxillofacial prostheses are nontoxic
Meran *et al.*, 2018	Ag	37 mm in diameter	Treated with 5 mL of 0.5% chlorhexidine digluconate for 5 min and then washed twice with 5 mlL of phosphate buffered solution	6	Antifungal and biocompatibility	Lactate dehydrogenase activity, ethanol assay	A-2186	Ag NPs are biocompatible with fibroblast cells in vitro and show antifungal properties

TiO_2: Titanium dioxide, Ag: Silver

least color changes.[6] Nano-TiO_2, ZnO, and CeO_2 are widely used as inorganic UV absorbers. UV absorbers do not migrate in a polymeric matrix, and their photo and thermal stability is not problematic even over decades. UV is an electromagnetic wave, when UV light acts on nanoparticles in the media; electrons among nanoparticles are forced to vibrate. Because the nanoparticles size is smaller than the UV wavelength, some parts of UV light are scattered and some parts are absorbed by nanoparticles simultaneously. Based on these physical principles, UV shielding is the result of nanoparticle absorption and scattering.[6] Addition of nano-oxides improves the color stability of the Cosmesil M511 elastomer in the study published by Akash and Guttal[7] Nano-ZnO-incorporated silicone showed no or minimal color changes.[7]

Bangera and Guttal evaluated the UV protecting capacity of nano-oxides in different concentrations and they reported that compared to TiO, ZnO in lesser concentration provided more consistent UV protection to Cosmesil M511 elastomer.[10] The efficiency of Zn oxide in providing the same amount of UV protection compared with larger concentrations of a Ti oxide provides an added advantage during color matching for the prostheses, because being too opaque makes shade matching to the skin difficult. ZnO nanoparticles absorb UV radiation. Since these ZnO nanoparticles are non-migratory in the matrix, they may be more effective and contribute to a longer service life. They also impart some degrees of transparency because of their nanometer scale and low content. As refractive index of nano-sized Ti oxide is high, they provide good UV protection by reflecting or scattering most of the UV rays.[10]

Biological properties

Since maxillofacial prosthesis is exposed to human saliva and nasal secretions, they are susceptible to microbial colonization, and also moisture, body temperature, and nutrient-rich residue from skin secretions promote fungal growth on the silicone prosthesis.[26,27] And also, the acidic pH of the facial skin makes it more susceptible to microbial colonization.[28] All these may lead to accelerated degradation of material and infection of the surrounding skin of that particular area.

Nanoparticles such as silver nanoparticles (Ag NPs) have fungicidal activity which can be used as a coating on the facial prosthesis as an antifungal agent.[19] Meran *et al.* coated Ag NPs on the surface of the silicone maxillofacial prosthesis and showed good antifungal activity of the Ag NPs without any adverse effects.[19] Akay *et al.* showed that nanoparticles such as nano-TiO_2, fumed silica, and silaned silica added to a silicone-based elastomer used for fabrication of maxillofacial prostheses are nontoxic.[29] Other nanoparticles like ZnO, CeO_2, $BaSO_4$, Al_2O_3, SiO_2, POSS which were used to improve the properties of silicone elastomer material requires evaluation of their biocompatibility in future research [Table 5].

The UV protecting nature of nanoparticles improves the color stability of the facial prosthesis made of silicone elastomer and also the improved mechanical properties and antifungal efficiency increases the longevity of the prosthesis. All these data obtained are from the *in vitro* studies; for more confirmatory results, clinical studies have to be conducted where the nanoparticle-incorporated silicone elastomer is used in the fabrication of facial prosthesis which exposed to real wear and tear process of prosthesis use by the patient.

Addition of various nanoparticles at a concentration ranging from 1% to 3% improved the hardness, tear strength, tensile strength, percentage elongation, and color stability. Nano-CeO_2 at a concentration of 1% improved the color stability and at 3% improved the hardness and tear strength. Nano-ZnO and TiO_2 at a concentration of 2% and 2.5% improved the hardness, tear strength, tensile strength, percentage elongation, and color stability.

CONCLUSION

With the available evidence of included *In-vitro* studies , it can be concluded that addition of nanoparticles at various concentrations may improve the color stability, hardness, tear strength, tensile strength, and percentage elongation of the prosthesis made from the silicone elastomer.

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Conflicts of interest
There are no conflicts of interest.

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