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
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 irreversibly altered.\(^4\)

Various methods have been tried to overcome this polymer deterioration such as addition of pigments and opacifiers, nanoparticles, and nano-oxides.\(^1,2,4\) 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.\(^4\)

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”) AND “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.

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) 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

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
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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. The environmental condition to which material exposes has an impact on amount of crosslinking, significantly affecting the physical and mechanical properties of the material.

Various nanoparticles such as Ti, Zn, Ce, BaSO₄, POSS, ceramic powder, and silica have evaluated for their effect on mechanical properties. Various nanoparticles such as Ti, Zn, Ce, BaSO₄, POSS, ceramic powder, and silica have evaluated for their effect on mechanical properties.

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.

The skin covering the orbital, nasal, and ear areas of the maxilla is thin and very close to the bone and cartilage. Thus, in order to mimic the texture of these sites, the silicone should exhibit hardness values between 25 and 35 Shore A. 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. 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.

The modulus of elasticity of silicone elastomer is proportional to the Shore A hardness, tear strength, tensile strength, and elongation. 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.

Addition of nano-sized oxides of Ti, Zn, or Ce at the concentrations of 2.0%–2.5% by...
weight increases the tear strength, tensile strength, and percentage elongation. Among the nanoparticles used, the nano-TiO\textsubscript{2} efficiently improves the mechanical properties due to their high specific surface area of nano-TiO\textsubscript{2} which is likely to reinforce the contact area and the extent of binding.\textsuperscript{[12]} However, at a concentration of more than 3\%, the same nanoparticles decreased the tear strength, tensile strength, and elongation.\textsuperscript{[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.\textsuperscript{[13]} 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.\textsuperscript{[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.\textsuperscript{[10,29]} 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.\textsuperscript{[14]} Zayed et al. employed this surface-treated SiO\textsubscript{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.\textsuperscript{[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.\textsuperscript{[8]} Sunlight is composed of many wavelengths such as infrared light, visible light, and UV light.\textsuperscript{[4]} 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.\textsuperscript{[4]}

Studies have shown that addition of nano-oxides to a silicone elastomer could improve its color stability [Table 4].\textsuperscript{[4,6,7,20,24,25]} Han et al. reported addition of 1% nano-CeO\textsubscript{2} and 2% and 2.5% nano-TiO\textsubscript{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 SiO2 | ASTM D412, ASTM D624, ASTM D2240 | - | 21 | TS, TRS, PE, H | Universal testing machine, Shore A durometer | A-2186 | Surface-treated SiO2 nanoparticles at a concentration of 3% enhanced the overall mechanical properties of A-2186 silicone elastomer. |
| Wang et al., 2014 | TiO2 | 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 7619-200B 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. |
| 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<sub>4</sub>, and TiO<sub>2</sub> | 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<sub>2</sub> nanoparticle addition exhibited hardness values lower than the clinically acceptable range, and BaSO<sub>4</sub> 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<sub>2</sub>, fumed silica, and silaned silica | ASTM D4 12, 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 TiO<sub>2</sub> for A-2000. The fumed hydrophilic silica group had significantly higher tensile strength than TiO<sub>2</sub> for A-2006. Most of silica specimens had higher tensile strength when compared with the control and TiO<sub>2</sub> groups for A-2000 and A-2006 silicones. The TiO<sub>2</sub> 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<sub>2</sub> | ISO 34-1, ISO 37, ISO 7691 | - | 40 | TRS, TS, PE, H | Universal testing machine, Shore A Durometer | Cosmesil M-511 | All nano-SiO<sub>2</sub> 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<sub>2</sub> | 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, PE, 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<sub>2</sub> | ASTM D624, ISO 37, ASTM D2240 | - | 10 | TRS, TS, PE, H | Universal testing machine, Shore A Durometer | VST 50 Cosmesil M511 | Nano-TiO<sub>2</sub> 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<sub>2</sub>; Titanium dioxide, ZnO: Zinc oxide, BaSO<sub>4</sub>; Barium sulfate, SiO<sub>2</sub>; Silicone dioxide, CeO<sub>2</sub>; Cerium dioxide. |
| 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$_2$ were 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 |
| Eltyayar NH et al., 2016 | TiO$_2$, Al$_2$O$_3$ | 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 |
| 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
Nano-\(\text{TiO}_2\), 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. Addition of nano-oxides improves the color stability of the Cosmesil M511 elastomer in the study published by Akash and Guttal. Nano-ZnO-incorporated silicone showed no or minimal color changes. Bangera and Guttal evaluated the UV protecting capacity of nano-oxides in different concentrations and they reported that compared to TiO\(_2\), ZnO in lesser concentration provided more consistent UV protection to Cosmesil M511 elastomer. 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.

#### 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. And also, the acidic pH of the facial skin makes it more susceptible to microbial colonization. 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. 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. Akay et al. showed

| Author and years | Type of nanoparticles | Dimensions of samples | Exposure | Test conditions | Properties | Result
|------------------|-----------------------|-----------------------|----------|----------------|------------|---------|
| Akay et al., 2016 | \(\text{TiO}_2\), fumed silica, and silaned silica | 2 mm height x 10 mm diameter | Autoclaved | 18 Cytotoxicity MTT assay | A-2000, A-2006 | Nanoparticles of \(\text{TiO}_2\), fumed silica, and silaned silica added to a commercial silicone-based elastomer used for fabrication of maxillofacial prostheses with fibroblast cells in vitro and show antifungal properties.

| Author and years | Type of nanoparticles | Dimensions of samples | Exposure | Test conditions | Properties | Result
|------------------|-----------------------|-----------------------|----------|----------------|------------|---------|
| 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 mL phosphate buffered solution | 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
that nanoparticles such as nano-TiO$_2$, fumed silica, and silanized silica added to a silicone-based elastomer used for fabrication of maxillofacial prostheses are nontoxic.\textsuperscript{[29]} Other nanoparticles like ZnO, CeO$_2$, BaSO$_4$, Al$_2$O$_3$, 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 \textit{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 \textit{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.

**REFERENCES**

1. Haug SP, Andres CJ, Moore BK. Color stability and colorant effect on maxillofacial elastomers. Part I: Colorant effect on physical properties. J Prostheth Dent 1999;81:418-22.
2. Zayed SM, Alshimy AM, Fahmy AE. Effect of surface treated silicon dioxide nanoparticles on some mechanical properties of maxillofacial silicone elastomer. Int J Biomater 2014;2014.
3. Kiat‑amnuay S, Mekkayarajjananonth T, Powers JM, Chambers MS and Lemon JC. Interaction of pigments and opacifiers on color stability of MDX4-4210/type A Maxillofacial elastomers on artificial ageing. J Prostheth Dent 2006;95:249-57.
4. Mouzakis DE, Papadopoulos TD, Polyzois GL, Griniari PG. Dynamic mechanical properties of a maxillofacial silicone elastomer incorporating a ZnO additive: The effect of artificial aging. J Craniofac Surg 2010;21:1867-71.
5. El‑Nour KM, Eftaiha AA, Al‑Warthan A, Ammar RA. Synthesis and applications of silver nanoparticles. Arab J Chem 2010;3:135-40.
6. 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 Suppl 2:e100-5.
7. 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.
8. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, et al. Preferred reporting items for systematic review and meta‑analysis protocols (PRISMA‑P) 2015 statement. Syst Rev 2015;4:1.
9. Higgins JP, Green S. Cochrane handbook for systematic reviews of interventions 4.2.6 [updated September 2006]. Cochrane Lib 2016;2006:4.
10. Kirthikadatta J, Gopikrishna V, Datta M. CRIS guidelines (Checklist for Reporting \textit{In‑vitro} Studies): A concept note on the need for standardized guidelines for improving quality and transparency in reporting \textit{in‑vitro} studies in experimental dental research. J Conserv Dent 2014;17:301-4.
11. Han Y, Kiat‑amnuay S, Powers JM, Zhao Y. Effect of nano‑oxide concentration on the mechanical properties of a maxillofacial silicone elastomer. J Prosthet Dent 2008;100:465-73.
12. Mohammad SA, Wee AG, Rumsey DJ, Schricker SR. Maxillofacial materials reinforced with various concentrations of polyhedral silsesquioxanes. J Dent Biometh 2010;2010.
13. Pesqueira AA, Goiato MC, Dos Santos DM, Haddad MF, Moreno A. Effect of disinfection and accelerated ageing on dimensional stability and detail reproduction of a facial silicone with nanoparticles. J Med Eng Technol 2012;36:217-21.
14. Bangera BS, Guttal SS. Evaluation of varying concentrations of nano‑oxides as ultraviolet protective agents when incorporated in maxillofacial silicones: An \textit{in vitro} study. J Prostheth Dent 2014;112:1567-72.
15. Wang L, Liu Q, Jing D, Zhou S, Shao L. Biomechanical properties of nano-TiO$_2$ addition to a medical silicone elastomer: The effect of artificial ageing. J Dent 2014;42:475-83.
16. Cevik P, Eraslan O. Effects of the addition of titanium dioxide and Silaned silica nanoparticles on the mechanical properties of maxillofacial silicones. J Prosthodont 2017;26:611-5.
17. Nobrega AS, Andretti AM, Moreno A, Sinhoretti 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 Prostheth Dent 2016;116:623-9.
18. Cevik P. Evaluation of Shore A hardness of maxillofacial silicones: The effect of dry storage and nanoparticles. Eur Oral Res 2018;52:99-104.
19. Meran Z, Besinis A, De Peralta T, Handy RD. Antifungal properties and biocompatibility of silver nanoparticle coatings on silicone maxillofacial prosthesis \textit{in vitro}. J Biomed Mater Res B Appl Biomater 2018;106:1038-51.
20. Bishal AK, Wee AG, Barão VA, Yuan JC, Landers R, Sukotjo C, et al. Dynamic mechanical properties of a maxillofacial silicone elastomer. J Prostheth Dent 2008;100:465-73.
21. Eltayaar NH, Alshimy AM, Abushelih MN. Evaluation of intrinsic color stability of facial silicone elastomer reinforced with different nanoparticles. Alexandria Dent Jo 2016;41:50-4.
22. Tukmachi M, Mouidhaffer M. Effect of nano silicon dioxide addition on some properties of heat vulcanized maxillofacial silicone elastomer. IOSR-JPBS 2017;12:37-43.
23. Azeem ZA, Tukmachi MS, Mohammed DH. Effect of silver-zinc zeolite addition on mechanical properties of maxillofacial silicone. Int J Med...
Res Health Sci 2018;7:19-29.

24. Korting HC, Braun-Falco O. The effect of detergents on skin pH and its consequences. Clin Dermatol 1996;14:23-7.

25. Filié Haddad M, Coelho Goiato M, Micheline Dos Santos D, Moreno A, Filipe D’almeida N, Alves Pesqueira A. Color stability of maxillofacial silicone with nanoparticle pigment and opacifier submitted to disinfection and artificial aging. J Biomed Opt 2011;16.

26. Shakir DA, Abdul-Ameer FM. Effect of nano-titanium oxide addition on some mechanical properties of silicone elastomers for maxillofacial prostheses. J Taibah Univ Med Sci 2018;13:281-90.

27. Kurtulmus H, Kumbuloglu O, Özean M, Oezdemir G, Vural C. Candida albicans adherence on silicone elastomers: Effect of polymerisation duration and exposure to simulated saliva and nasal secretion. Dent Mater 2010;26:76-82.

28. Leow ME, Kour AK, Inglis TJ, Kumarasinghe G, Pho RW. Fungal colonisation in digital silicone rubber prostheses. Prosthet Orthot Int 1997;21:195-8.

29. Akay C, Cevik P, Karakis D, Sevim H. In vitro cytotoxicity of maxillofacial silicone elastomers: Effect of nano-particles. J Prosthodont 2018;27:584-7.

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