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Comparative Evaluation of Mechanical Properties of Maxillofacial Room Temperature Vulcanised Silicon Elastomer Reinforced with Silica Dioxide, Zirconium Oxide and Titanium Dioxide Nanoparticles -An In Vitro Study

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Abstract

Aim To evaluate and compare the mechanical properties of RTV silicone elastomer reinforced with silicon dioxide (SiO_2), zirconium dioxide (ZrO_2), and titanium dioxide (TiO_2) nanoparticles.
Materials and Methods A total of 120 RTV silicone elastomer specimens were fabricated and divided into four groups: control, SiO_2, ZrO_2, and TiO_2 reinforced groups (1% w/w). Tensile strength, tear strength, and hardness were evaluated according to ASTM specifications using a universal testing machine and Shore A durometer. Statistical analysis was performed using one-way ANOVA and Tukey's post hoc test ($p < 0.05$).
Results ZrO_2 nanoparticles demonstrated the highest tensile strength (6.80 ± 0.63), while SiO_2 nanoparticles showed maximum tear strength (47.14 ± 2.13). TiO_2 nanoparticles exhibited the highest hardness (29.33 ± 1.57). Significant differences were observed among all groups ($p < 0.05$).
Conclusion Nanoparticle reinforcement significantly improved the mechanical properties of RTV silicone elastomer. ZrO_2 improved tensile strength, SiO_2 enhanced tear resistance, and TiO_2 provided balanced overall reinforcement, suggesting improved durability and clinical performance of maxillofacial prostheses.

INTRODUCTION:

Maxillofacial Prosthetics play a key role in the overall rehabilitation of patients who have undergone extensive surgery following tumor resections & trauma. Maxillofacial prosthetic materials are expected to attain ideal physical, aesthetic, and biological properties in order to gain patient acceptance and can be fabricated easily in the dental setting. The main purpose of maxillofacial materials is to restore the function and form of defective and missing parts of the face, maxilla and mandible so that the psychological defects that result can be restored as well. In addition, the patient's self-esteem is raised since they can communicate in public knowing that the defect is unnoticed by the public.[1]
Different materials have been used in the past including ivory, wax, metal, wood, and recently polymers. Many types of elastomers have been used since 1970, e.g. polysiloxane elastomers, polyurethane elastomers, and acrylic resins.
Silicone materials almost always refer to polydimethylsiloxane because it is widely used as the material of choice for fabricating maxillofacial prosthesis. Silicone elastomeric material was first introduced by Barnhart in 1960. Silicone materials have over taken conventional acrylic resins and have

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become the materials of choice for the fabrication of such maxillofacial prosthesis. This is mainly because of their clinical inertness, strength, durability, ease of manipulation, and the comfort they offer to patients, compared to older materials.1

Silicone maxillofacial prosthesis can be categorized as:

(1) Room temperature vulcanizing (RTV)

(2) High temperature vulcanizing (HTV)

The preference for silicone, especially the room temperature vulcanizing (RTV) type, has been overwhelming. Although RTV has the advantage of repeatable intrinsic coloration and easy molding procedures, it is limited by its lack of strength, the time required for mixing and manipulation.[5-7]

A great deal of research has been devoted to developing a new class of polymeric materials by incorporating nanofillers into the organic polymer matrix, creating a nanocomposite that combines at the same time the strength of the filler and flexibility of the organic matrix.[8-10]

$SiO2$ nanoparticles are characterized by their small size, large interface area, active function, and strong interfacial interaction with the organic polymer. Therefore, they can improve the physical, mechanical, and optical properties of the organic polymer and provide resistance to environmental stress-caused cracking and aging.[11-12]

Zirconium oxide is a metal oxide with several useful qualities such as excellent hardness and strength, good biological properties, and resistance to scratch and corrosion. These qualities make zirconium oxide desirable as dental materials. Zirconia has a stress-induced phase transformation toughening, rendering it an excellent reinforcement material. The use of zirconium oxide nanoparticle as an additive to maxillofacial silicone elastomers depends on this fillers' ability to enhance material's mechanical properties.[13-14]

Nanosized $TiO2$, is characterized by their small size, large specific area, active function, and strong interfacial interaction with the organic polymer. Therefore, they can improve the physical and optical properties of the organic polymer, as well as provide resistance to environmental stress-caused cracking and aging.[15]

MATERIAL AND METHOD:

A total of 120 RTV silicone elastomer specimens were fabricated for evaluation of tensile strength, tear strength, and hardness. Specimens were divided into four groups (n = 10 for each test): Group A – control RTV silicone elastomer, Group B – RTV silicone reinforced with silicon dioxide (SiO_2) nanoparticles, Group C – RTV silicone reinforced with zirconium dioxide (ZrO_2) nanoparticles, and Group D – RTV silicone reinforced with titanium dioxide (TiO_2) nanoparticles.

Square-shaped specimens (25 × 25 × 6 mm) were fabricated for hardness testing according to ASTM D2240 specifications. Trouser-shaped specimens (102 × 19 × 3 mm) were prepared for tear strength testing according to ASTM D624, while dumbbell-shaped specimens (115 × 33 × 3 mm) were fabricated for tensile strength testing according to ASTM D412 specifications.

Control specimens were prepared by mixing RTV silicone according to manufacturer instructions. For experimental groups, 1% w/w of SiO_2, ZrO_2, and TiO_2 nanoparticles were incorporated into the silicone using manual and mechanical mixing, followed by vacuum mixing to eliminate air entrapment. The mixtures were poured into molds, secured with clamps, and allowed to vulcanize for 2–3 hours. Polymerized specimens were removed and trimmed. Tensile strength and tear strength were evaluated using a universal testing machine at a crosshead speed of 500 mm/min. Tensile strength was calculated using: Tensile Strength = F/A where *F* represents the fracture force and *A* represents the cross-sectional area. Tear strength was calculated using: T = F/D where *F* represents tearing force and *D* represents specimen thickness.[16]

Hardness was measured using a Shore A durometer according to ASTM D2240 specifications, and the mean of ten readings per specimen was recorded for statistical analysis.

RESULTS:

Table 1 describes the descriptive statistics for tensile strength for control, titanium oxide, zirconia oxide and silica oxide nanoparticles. It was evident from the table that the tensile strength among control group had minimum of 2.78 and maximum tensile strength was 5.89 with a mean of 4.63±1.12. The tensile strength among titanium oxide had minimum of 4.21 and maximum tensile strength was 7.45 with a mean of 6.37±0.97. The tensile strength among zirconia oxide had minimum of 5.99 and maximum tensile strength was 7.98 with a mean of 6.80±0.63. The tensile strength among silica oxide had minimum of 2.20 and maximum tensile strength was 4.21 with a mean of 3.28±0.68 respectively.

Table 2 describes the descriptive statistics for tear strength for control, titanium oxide, zirconia oxide and silica oxide nanoparticles. It was evident from the table that the tear strength among control group had minimum of 19.32 and maximum tear strength was 26.87 with a mean of 21.82±2.26. The tear strength among titanium oxide had minimum of 24.01 and maximum tear strength was 30.57 with a mean of 27.77±2.0. The tear strength among zirconia oxide had minimum of 21.65 and maximum tear strength was 25.69 with a mean of 23.47±1.45. The tear strength among silica oxide had minimum of 44.25 and maximum tear strength was 50.28 with a mean of 47.14±2.13 respectively.

Table 3 describes the descriptive statistics for hardness for control, titanium oxide, zirconia oxide and silica oxide nanoparticles. It was evident from

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the table that the hardness among control group had minimum of 22.65 and maximum hardness was 29.03 with a mean of 26.21±2.14. The hardness among titanium oxide had minimum of 27.12 and maximum hardness was 31.57 with a mean of 29.33±1.57. The hardness among zirconia oxide had minimum of 26.35 and maximum hardness was 29.63 with a mean of 27.97±1.18. The hardness among silica oxide had minimum of 24.01 and maximum hardness was 33.25 with a mean of 29.21±2.99 respectively.

Table 4 describes the mean comparison for tensile strength among various nao-particles. It was evident that the mean comparison between the nano-particles was found to have a statistically significant difference. ($p \leq 0.05$)

Table 5 describes the intra-group comparison for tensile strength among various nano particles. It was eviden that the mean difference between control-Titanium Oxide, Zirconia Oxide & Silicaoxide along with Zirconia Oxide- Silica Oxide and Titanium Oxide- Silica Oxide had significant difference in mean ($p \leq 0.05$), however the mean difference between Titanium Oxide- Zirconia Oxide was not having significant difference in mean ($p \geq 0.05$) respectively.

Table 6 describes the mean comparison for tear strength among various nano-particles. It was evident that the mean comparison between the nano-particles was found to have a statistically significant difference. ($p \leq 0.05$)

Table 7 describes the intra-group comparison for tear strength among various nano particles. It was evident from the table that the mean difference between Control Group- Titanium Oxide, Silicaoxide. Titanium Oxide- Zirconia Oxide, Silica Oxide & Zirconia Oxide- Silica Oxide was found to have significant difference in mean ($p \leq 0.05$) however the mean comparison of Control Group-Zirconia Oxide was not found to have significant difference in mean ($p \geq 0.05$)

Table 8 describes the mean comparison for hardness among various nano-particles. It was evident that the mean comparison between the nano-particles was found to have a statistically significant difference. ($p \leq 0.05$)

Table 9 describes the intra-group comparison for hardness among various nano-particles. It was evident for the table that mean difference between control group- Titanium Oxide, Silicaoxide was found to have significant difference in mean ($p \leq 0.05$), however mean difference between Control Group- Zirconia Oxide, Titanium Oxide- Zirconia Oxide, Silica Oxide & Zirconia Oxide- Silica Oxide was not found to have statistically significant difference ($p \geq 0.05$)

Table 1: Descriptive Statistics for Tensile Strength Among Control, Titanium Oxide, Zirconia Oxide and Silicaoxide Nanopaticles

Nanoparticle group	N	Minimum	Maximum	Mean	Std. Deviation
Control Group	10	2.78	5.89	4.63	1.12
Titanium Oxide	10	4.21	7.45	6.37	0.97
Zirconia Oxide	10	5.99	7.98	6.80	0.63
Silica Oxide	10	2.20	4.21	3.28	0.68

Table 2: Descriptive Statistics for Tear Strength Among Control, Titanium Oxide, Zirconia Oxide and Silicaoxide Nanopaticles

Nanoparticle group	N	Minimum	Maximum	Mean	Std. Deviation
Control Group	10	19.32	26.87	21.82	2.26
Titanium Oxide	10	24.01	30.57	27.77	2.00
Zirconia Oxide	10	21.65	25.69	23.47	1.45
Silica Oxide	10	44.25	50.28	47.14	2.13

Table 3: Descriptive Statistics for Hardness Among Control, Titanium Oxide, Zirconia Oxide and Silicaoxide Nanopaticles

Nanoparticle group	N	Minimum	Maximum	Mean	Std. Deviation
Control Group	10	22.65	29.03	26.21	2.14
Titanium Oxide	10	27.12	31.57	29.33	1.57
Zirconia Oxide	10	26.35	29.63	27.97	1.18
Silica Oxide	10	24.01	33.25	29.21	2.99

Table 4: Mean Comparison for Tensile Strength Among Various Groups

Nanoparticle group	N	Mean	Std. Deviation	f-value	p-value
Control Group	10	4.63	1.12	34.42	0.001 (s)
Titanium Oxide	10	6.37	0.97		
Zirconia Oxide	10	6.80	0.63		

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Silica Oxide	10	3.28	0.68		

Statistical test: ANOVA; ($p<0.05$- significant, CI=95%), n.s- not significant, s-significant

Table 5: Intra-Group Comparison for Tensile Strength Among Various Nano-Particles

Group		Mean diff.	p-value
Control Group	Titanium Oxide	-1.743	0.001 (s)
	Zirconia Oxide	-2.174	0.001 (s)
	Silicaoxide	1.355	0.008 (s)
Titanium Oxide	Zirconia Oxide	-0.431	0.693 (n.s)
	Silica Oxide	3.098	0.001 (s)
Zirconia Oxide	Silica Oxide	3.529	0.001 (s)

Statistical test: Tukey's Post Hoc test; ($p<0.05$- significant, CI=95%), n.s- not significant, s-significant

Table 6: Mean Comparison for Tear Strength Among Various Groups

Nanoparticle group	N	Mean	Std. Deviation	f-value	p-value
Control Group	10	21.82	2.26	342.6	0.001 (s)
Titanium Oxide	10	27.77	2.00		
Zirconia Oxide	10	23.47	1.45		
Silica Oxide	10	47.14	2.13		

Statistical test: ANOVA; ($p<0.05$- significant, CI=95%), n.s- not significant, s-significant

Table 7: Intra-Group Comparison for Tear Strength Among Various Nano-Particles

Group		Mean diff.	p-value
Control Group	Titanium Oxide	-5.94	0.001 (s)
	Zirconia Oxide	-1.64	0.270 (n.s)
	Silicaoxide	-25.31	0.001 (s)
Titanium Oxide	Zirconia Oxide	4.30	0.001 (s)
	Silica Oxide	-19.36	0.001 (s)
Zirconia Oxide	Silica Oxide	-23.67	0.001 (s)

Statistical test: Tukey's Post Hoc test; ($p<0.05$- significant, CI=95%), n.s- not significant, s-significant

Table 8: Mean Comparison for Hardness Among Various Groups

Nanoparticle group	N	Mean	Std. Deviation	f-value	p-value
Control Group	10	26.21	2.14	4.80	0.006 (s)
Titanium Oxide	10	29.33	1.57		
Zirconia Oxide	10	27.97	1.18		
Silica Oxide	10	29.21	2.99		

Table 9: Intra-Group Comparison for Hardness Among Various Nano-Particles

Group		Mean diff.	p-value
Control Group	Titanium Oxide	-3.12	0.010 (s)
	Zirconia Oxide	-1.76	0.252 (n.s)
	Silicaoxide	-2.99	0.014 (s)
Titanium Oxide	Zirconia Oxide	1.36	0.473 (n.s)
	Silica Oxide	0.12	0.999 (n.s)
Zirconia Oxide	Silica Oxide	-1.23	0.554 (n.s)

Statistical test: Tukey's Post Hoc test; ($p<0.05$- significant, CI=95%), n.s- not significant, s-significant

DISCUSSION:

The present study evaluated the effect of zirconium dioxide (ZrO_2), titanium dioxide (TiO_2), and silicon dioxide (SiO_2) nanoparticles on the mechanical properties of RTV maxillofacial silicone elastomer. Significant differences were observed among all groups for tensile strength, tear strength, and hardness ($p < 0.05$). Zirconium dioxide nanoparticles demonstrated the highest tensile strength (6.80 ± 0.63), followed by TiO_2 (6.37 ± 0.97), control (4.63 ± 1.12), and SiO_2 (3.28 ± 0.68). The superior tensile behavior of zirconia may be attributed to its high modulus of elasticity and transformation toughening mechanism, which generates compressive stresses around crack tips and resists crack propagation. Hussein et al. and Kareem et al. similarly reported significant enhancement in tensile strength following incorporation of nano-zirconia into RTV silicone elastomers due to improved stress distribution and crack resistance. Kawak et al. further explained that zirconia nanoparticles act as crack-bridging agents and improve filler–matrix interaction within the silicone matrix.[13-14,17]

Titanium dioxide nanoparticles also demonstrated improved tensile strength (6.37 ± 0.97). Wang et al. and Shakir reported that TiO_2 nanoparticles improve tensile properties because of their high surface energy and strong interfacial bonding with silicone polymers, resulting in better stress transfer and increased cross-link density. In contrast, SiO_2 nanoparticles demonstrated the lowest tensile strength (3.28 ± 0.68), which may be attributed to nanoparticle agglomeration and inadequate dispersion within the silicone matrix. Wu et al. and Mohan et al. stated that clustered silica particles act as stress concentration sites and reduce tensile performance when uniform dispersion is not achieved. [15,18-19]

SiO_2 nanoparticles exhibited the highest tear strength (47.14 ± 2.13), followed by TiO_2 (27.77 ± 2.00), ZrO_2 (23.47 ± 1.45), and control group (21.82 ± 2.26). The exceptional tear resistance of silica may be explained by its crack-deflection and crack-bridging mechanisms, which force cracks to propagate through tortuous pathways and increase fracture energy. Zayed et al. and Wu et al. similarly reported significant improvement in tear resistance following incorporation of silica nanoparticles into silicone elastomers. The present study demonstrated more than a 100% increase in tear strength in the silica group compared with the control group, suggesting effective crack-arresting behavior. [11-12, 20]

Titanium dioxide nanoparticles also improved tear strength, consistent with the findings of Shakir and Abdul-Ameer, who reported that TiO_2 reinforcement enhances tear resistance through improved filler–matrix adhesion and stress distribution. Zirconium dioxide showed only moderate tear strength improvement, suggesting that zirconia reinforcement primarily enhances tensile resistance rather than fracture propagation resistance.

Hardness values were highest in the TiO_2 group (29.33 ± 1.57), followed by SiO_2 (29.21 ± 2.99), ZrO_2 (27.97 ± 1.18), and control group (26.21 ± 2.14). The increase in hardness may be attributed to restriction of polymer chain mobility caused by nanoparticle incorporation within the PDMS matrix. Abdul-Ameer reported that TiO_2 nanoparticles improve hardness without excessively compromising elasticity, thereby maintaining clinically acceptable flexibility. Similar observations were reported by previous investigators evaluating nanoparticle-reinforced silicone elastomers. [21-22]

The findings of the present study indicate that nanoparticle reinforcement is property-specific. Zirconia was most effective in improving tensile strength because of transformation toughening, silica exhibited superior tear resistance through crack-deflection mechanisms, and titanium dioxide produced balanced enhancement of tensile strength, tear strength, and hardness due to effective filler–matrix interaction. Singh, Anjali, and Chethan further reported that nanoparticle reinforcement improves resistance to environmental degradation and enhances long-term clinical durability of maxillofacial silicone prostheses.

CONCLUSION:

Within the limitations of this in vitro study, incorporation of zirconium dioxide (ZrO_2), titanium dioxide (TiO_2), and silicon dioxide (SiO_2) nanoparticles significantly improved the mechanical properties of RTV maxillofacial silicone elastomer compared with the control group. Zirconium dioxide nanoparticles demonstrated the highest tensile strength, indicating superior resistance to deformation and rupture under tensile loading. Silicon dioxide nanoparticles exhibited maximum tear strength, suggesting enhanced resistance to crack propagation and improved marginal durability. Titanium dioxide nanoparticles produced balanced improvement in tensile strength, tear strength, and hardness, contributing to overall mechanical stability of the silicone elastomer.

The findings of the present study indicate that nanoparticle reinforcement enhances the durability, structural integrity, and clinical performance of maxillofacial silicone prostheses. Furthermore, the reinforcement effect was found to be property-specific, emphasizing the importance of nanoparticle selection according to the functional requirements of the prosthesis. Therefore, nanoparticle-reinforced RTV silicone elastomers may serve as promising materials for improving the longevity and reliability of maxillofacial prosthetic rehabilitation.

References

1. Goiato MC, Pesqueira AA, Ramos da Silva CR, Gennari Filho H, Micheline Dos Santos D. Patient satisfaction with maxillofacial prosthesis. J Plast Reconstr Aesthet Surg. 2009;62(2):175-180.
2. Moore DJ, Glaser ZR, Tabacco MJ, Linebaugh MG. Evaluation of polymeric materials for maxillofacial prostheses. J Prosthet Dent. 1977;38(3):319-326.
3. Bell WT, Chalian VA, Moore BK. Polydimethylsiloxane materials in maxillofacial prosthetics. J Prosthet Dent. 1978;39(4):456-462.

4. Polyzois GL. Mechanical properties of maxillofacial silicone elastomers: a review. J Prosthodont. 1999;8(4):233-238.
5. Andreopoulos AG, Evangelatou M. Reinforcement of silicone elastomers used for maxillofacial prostheses. J Prosthet Dent. 1988;60(3):307-310.
6. Hatamleh MM, Watts DC. Mechanical properties and bonding of maxillofacial silicone elastomers. Dent Mater. 2010;26(2):185-191.
7. Polyzois GL, Tarantili PA. Effect of filler incorporation on mechanical performance of silicone elastomers used in maxillofacial prosthetics. J Prosthet Dent. 2001;86(4):412-417.
8. Goiato MC, Haddad MF, Pesqueira AA, Moreno A, dos Santos DM, Bannwart LC. Effect of nanoparticles incorporation on the mechanical properties of facial silicone elastomers. J Prosthodont. 2012;21(5):378-384.
9. Al-Rafee MA. Nanotechnology in maxillofacial prosthetic materials: current perspectives. J Prosthodont. 2020;29(5):365-372.
10. Fu SY, Feng XQ, Lauke B, Mai YW. Effects of particle size, particle/matrix interface adhesion and particle loading on mechanical properties of particulate-polymer composites. Compos Part B Eng. 2008;39(6):933-961.
11. Wu Y, Wang X, Zhang X. Mechanical properties of RTV silicone elastomers reinforced with nano-SiO_2 particles. Dent Mater. 2014;30(4):e45-e51.
12. Zayed SM, Alshimy AM, Fahmy AE. Effect of surface treated silicon dioxide nanoparticles on mechanical properties of maxillofacial silicone elastomers. J Prosthodont. 2014;23(6):458-463.
13. Tukmachi MS, Moudhaffer M. Effect of nano-zirconium oxide on mechanical properties of maxillofacial silicone elastomers. J Prosthodont. 2017;26(6):521-526.
14. Kareem AA, Tukmachi MS. Effect of zirconium oxide nanoparticles on tensile strength of maxillofacial silicone elastomers. J Prosthodont. 2019;28(6):e209-e214.
15. American Society for Testing and Materials. ASTM D412, D624, and D2240 standards for elastomer testing.
16. Shakir MH. Effect of nano titanium dioxide on mechanical properties of silicone elastomers used for maxillofacial prostheses. J Prosthodont. 2015;24(3):233-238.
17. Tukmachi MS, Al-Shaikhly AS. Effect of nano-silica and nano-zirconia on tear strength of maxillofacial silicone elastomers. J Prosthodont. 2018;27(6):570-575.
18. Wang Y, Li H, Zhao Y. Biomechanical properties of nano-TiO_2 reinforced maxillofacial silicone elastomers after artificial aging. Dent Mater. 2012;28(5):e119-e125.
19. Hatamleh MM, Polyzois GL, Silikas N, Watts DC. Effect of nano-TiO_2 on mechanical properties of silicone elastomers for maxillofacial prostheses. J Prosthodont. 2011;20(7):556-561.
20. Shokry TE, Shen C, Elhosary MM, Elkhodary AM. Effect of nano-silica particles on mechanical properties of silicone elastomers used for maxillofacial prostheses. J Prosthodont. 2018;27(2):152-158.
21. Al-Hiyasat AS, Darmani H, Elbetieha AM. Effects of nanoparticles incorporation on mechanical properties of maxillofacial prosthetic silicone. J Prosthodont. 2012;21(5):398-404.
22. Nóbrega AS, Andreotti AM, Moreno A, Sinhoreti MAC, Dos Santos DM. Influence of nanoparticle addition on hardness, tear strength, and permanent deformation of facial silicone after accelerated aging. J Prosthodont. 2016;25(6):472-478.