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Comparative Evaluation of Incorporation of Graphene Nanoparticle on Tear Strength, Tensile Strength, Percent Elongation and Hardness of Maxillofacial Silicone Elastomeric Material: An *in-vitro* Study

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ABSTRACT

Background: Maxillofacial silicone elastomers are widely used for facial prostheses; however, their clinical longevity is limited due to poor tear strength and mechanical degradation.
Aim: To evaluate and compare the effect of graphene nanoparticle incorporation on mechanical properties of maxillofacial silicone elastomer.
Materials and Methods: A total of 120 silicone samples were fabricated and divided into control and graphene-reinforced groups (0.5 wt%). Each group was subdivided based on tests: tear strength, tensile strength, elongation, and hardness. Mechanical testing was performed using a universal testing machine and Shore A durometer following ASTM standards.
Statistical analysis was done using ANOVA and independent t-test.
Results: Graphene incorporation significantly improved tear strength, tensile strength, and elongation, while reducing hardness. The differences were statistically significant ($p < 0.001$).
Conclusion: Graphene nanoparticles enhance mechanical properties of maxillofacial silicone elastomers and can improve clinical durability of prostheses.

Keywords: Graphene nanoparticles, Maxillofacial silicone, Tear strength, Tensile strength, Percent Elongation, Hardness, Elastomer.

INTRODUCTION

Maxillofacial defects caused by congenital anomalies, trauma, tumor resection, or disease can result in significant functional, esthetic, and psychological challenges, affecting speech, mastication, and social interaction. Maxillofacial prosthetic rehabilitation aims to restore facial form, improve function, and enhance patient confidence, especially when surgical reconstruction is not feasible or satisfactory. [1, 2]

Silicone elastomers are the most widely used materials for extraoral prostheses due to their excellent biocompatibility, flexibility, chemical stability, and lifelike appearance. Their viscoelastic nature allows them to mimic soft tissue behavior, while their siloxane structure provides thermal stability and environmental resistance. RTV silicones are commonly used clinically due to ease of processing, whereas HTV silicones offer superior mechanical properties. [3,4, 5]

An ideal silicone should exhibit adequate softness, tear resistance, elasticity, and dimensional stability while maintaining esthetics. However, current materials have limitations, particularly low tear strength at thin margins, leading to frequent clinical failures. [2, 6] Environmental factors such as UV radiation, humidity, and temperature variations further accelerate degradation, causing discoloration and mechanical weakening over time. [3, 7]

Mechanical properties such as tear strength, tensile strength, percentage elongation, and hardness are critical for prosthesis longevity. [3, 6] to improve these properties, reinforcement using fillers has been explored. Conventional fillers have limited success, whereas nanoparticles offer better reinforcement due to their high surface area and improved interaction with polymer chains. [8]

Various nanoparticles like TiO_2, SiO_2, ZnO, and $BaTiO_3$ have shown improvements in mechanical properties; however, higher concentrations may lead to agglomeration, increased hardness, and reduced elasticity. [9,10,11]

Graphene, a two-dimensional nanomaterial with exceptional strength and large surface area, provides effective reinforcement even at low concentrations by enhancing stress transfer and preventing crack propagation. [12, 13]

Although graphene shows promising results in improving mechanical properties, comprehensive evaluation in maxillofacial silicone elastomers remains limited. [14] Therefore, the present in-vitro study aims to assess the effect of graphene nanoparticle incorporation on tensile strength, tear strength, percentage elongation, and Shore A hardness to determine its suitability as a reinforcing agent.

Maxillofacial defects caused by trauma, congenital anomalies, or surgical resection significantly affect esthetics, function, and psychological well-being of patients. Prosthetic rehabilitation using silicone elastomers plays a crucial role in restoring facial form and function. Silicone elastomers are preferred due to their flexibility, biocompatibility, and life-like appearance. However, their clinical performance is compromised by poor mechanical properties such as low tear strength and tensile strength, leading to frequent prosthesis failure. Tear failure at thin margins is the most common cause of deterioration. Hence, improving the mechanical properties of silicone elastomers remains a major research focus. Recent advancements in nanotechnology have introduced nanoparticle reinforcement as an effective method to enhance material properties. Graphene, a two-dimensional carbon nanomaterial, possesses exceptional mechanical strength, high surface area, and excellent interaction with polymer matrices. This study aims to evaluate the effect of graphene nanoparticle incorporation on mechanical properties of maxillofacial silicone elastomers.

MATERIALS & METHODS

Study Design:

In vitro experimental study.

Materials Used:

1. Silicone elastomer material (MP Sai Enterprise, Thane)
2. Graphene oxide nanoparticle (Nano Research Lab, Jharkhand).

3. Dental modelling wax (Dental products of India Ltd.)
4. Model plaster (Kalrock, Kalabhai Karson Pvt Ltd, Mumbai)
5. Petroleum jelly (Eastwin Laboratories, India)
6.

Equipment used:

- Electro Mechanical Universal Testing Machine (Instron EM-100)
- Shore A durometer (TIRE Duro A)

Standardized Die Preparation

A custom stainless steel master die was fabricated to obtain standardized silicone specimens for mechanical testing:

- Tensile strength & elongation (ASTM D412): 25 ± 3 mm × 25 ± 3 mm × 3 ± 0.5 mm
- Tear strength (ASTM D624): 65 mm × 10 mm × 3 mm
- Shore A hardness (ASTM D2240): 30 mm × 3 mm

Sample Preparation:

Mold spaces were prepared by investing stainless steel dies in type II dental plaster. After setting, dies were removed and a separating medium was applied. A total of 120 silicone elastomer samples were fabricated, including 60 graphene-reinforced specimens (0.5 wt%). Graphene oxide nanoparticles were weighed accurately and incorporated into silicone using manual mixing followed by vacuum mixing to ensure uniform dispersion and eliminate air entrapment. Then it was poured into molds, flasked, and allowed to polymerize at room temperature for 24 hours. Samples were then retrieved, trimmed, and finished.

Grouping of Samples:

Samples were divided into two groups (n = 60 each):

- **Group A:** Control Group silicone without Graphene
- **Group B:** Test Group Graphene-reinforced silicone

Each group was subdivided into:

- Tear strength (n = 20)
- Tensile strength & Elongation (n = 20)
- Hardness (n = 20)

Testing Procedures:

Testing was performed using a universal testing machine at a crosshead speed of 500 mm/min. (Figure 1,2,3)

Tensile strength was calculated using: **Ts (MPa) = F / (W × T)**

Elongation at break was calculated as: **Elongation (%) = [(Lb − Lo) / Lo] × 100**

Tear strength (N/mm) = F / d

Hardness was measured using a Shore A durometer. Six readings were taken per specimen and averaged.

Fig 1

Fig 2

Fig 3

Fig 1,2,3: Testing of samples

Statistical Analysis

Data was analyzed using ANOVA and independent t-test with significance set at $p < 0.05$.

RESULT

The incorporation of graphene nanoparticles into the silicone elastomer resulted in a statistically significant improvement in mechanical properties. (Table 1) Tear strength showed a marked increase, indicating enhanced resistance to crack propagation and improved durability of the material (Fig 4). Tensile strength was significantly higher in the graphene group, demonstrating better load-bearing capacity (Fig 5). Elongation percentage increased, suggesting improved elasticity and flexibility without compromising structural integrity (Fig 6). Hardness showed a slight but significant decrease, indicating increased softness and flexibility, which may enhance marginal adaptation and patient comfort (Fig 7). Overall, graphene reinforcement produced a stronger, more elastic, and clinically durable silicone material, with improved resistance to mechanical failure.

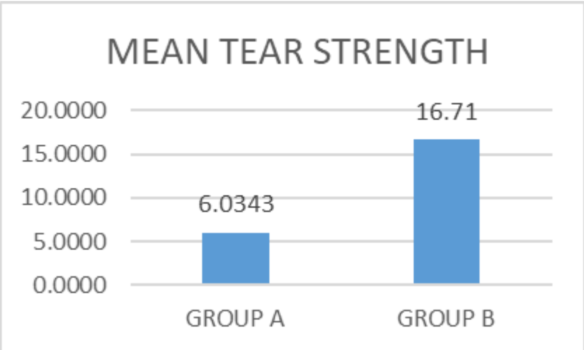

Fig 4: Mean Tear Strength

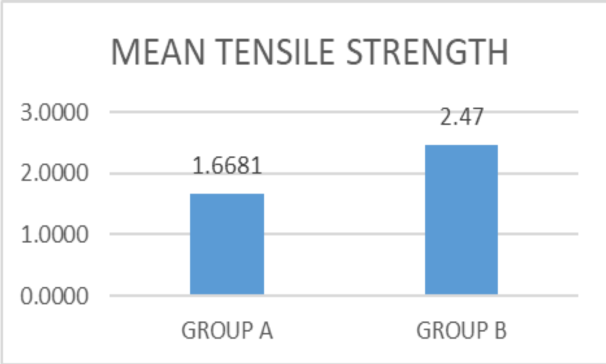

Fig 5: Mean Tensile Strength

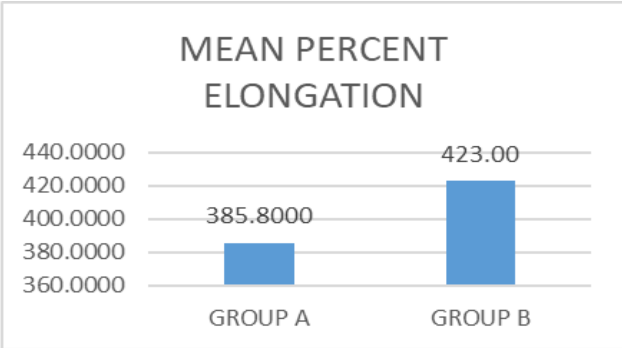

Fig 6: Mean Percent Elongation

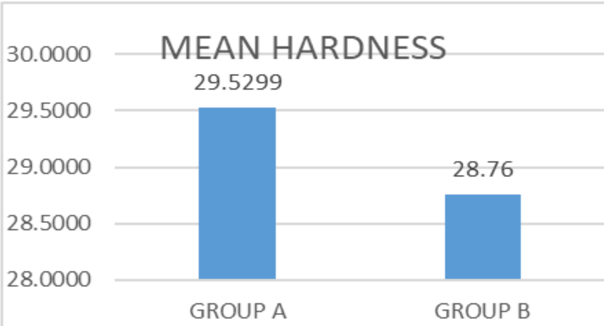

Fig 7: Mean Hardness

TABLE 1: DESCRIPTIVE STATISTICS OF ALL TESTED GROUPS

	GROUPS	N	MEAN	Std. Deviation	Std. Error Mean	T VALUE	P VALUE
TEAR STRENGTH	A	20	6.0361	.01253	.00304	-96.470	.000
	B	20	15.6750	.41093	.09189		
TENSILE STRENGTH	A	20	1.6735	.03704	.00898	-19.943	.000
	B	20	2.2662	.11745	.02626		
PERCENT ELONGATION	A	20	385.7647	.90342	.21911	-93.292	.000
	B	20	421.0500	1.31689	.29447		
HARDNESS	A	20	29.5166	.77791	.18867	9.372	.000
	B	20	27.1020	.78354	.17520		

DISCUSSION

Maxillofacial prosthetic rehabilitation remains essential for restoring esthetics, function, and psychosocial well-being, particularly in patients where surgical reconstruction is limited or contraindicated.

Silicone elastomers are considered the material of choice due to their superior esthetic qualities, flexibility, and biocompatibility. However, their long-term clinical performance is compromised by issues such as marginal tearing, discoloration, loss of elasticity, and gradual mechanical degradation, often requiring replacement within 6 months to 2 years.[5, 15]

The durability of these prostheses largely depends on key mechanical properties, including tensile strength, tear strength, percentage elongation, and hardness.[16] Tensile strength determines resistance to rupture under functional stresses, while tear strength is critical in preventing failure at thin prosthetic margins. Percentage elongation ensures flexibility during facial movements, and hardness influences both durability and lifelike tissue simulation.

To overcome the inherent limitations of silicone, nanoparticle reinforcement has been widely investigated. Among various nanofillers, graphene has shown significant potential due to its exceptional mechanical properties, including high tensile strength and Young's modulus, along with its large surface area and two-dimensional structure.[17,18,19,20] These characteristics enable effective stress distribution, strong interfacial bonding with the silicone matrix, and enhanced crack resistance.

In the present study, incorporation of graphene nanoparticles resulted in a statistically significant improvement in tensile strength, tear strength, and percentage elongation, while maintaining hardness within clinically acceptable limits. The reinforcement mechanism is attributed to efficient stress transfer, reduced polymer chain slippage, and crack-bridging and crack-deflection effects. [17,18,19,20] Unlike conventional fillers such as TiO_2 and SiO_2, which may agglomerate at higher concentrations, graphene provides effective reinforcement even at lower concentrations.[21,22]

From a clinical perspective, these improvements translate into better resistance to rupture during handling, enhanced flexibility for facial expressions, and reduced marginal tearing, thereby potentially extending the service life of maxillofacial prostheses. Nevertheless, limitations such as the absence of artificial aging, UV exposure simulation, cytotoxicity evaluation, and color stability analysis must be addressed in future studies to validate long-term clinical applicability.[5,15,23]

CONCLUSION

Within the limitations of this in-vitro study, it can be concluded that:

1. Incorporation of graphene nanoparticles into maxillofacial silicone elastomer significantly enhances tear strength, tensile strength, and percent elongation.
2. Graphene reinforcement improves resistance to crack initiation and propagation, thereby potentially increasing prosthesis durability.
3. A slight but statistically significant reduction in Shore A hardness was observed after graphene incorporation; however, the material maintained clinically acceptable hardness values.
4. Proper dispersion and controlled concentration of nanoparticles are critical for achieving optimal reinforcement.
5. Graphene nanoparticles represent a promising reinforcing agent for improving the mechanical performance of maxillofacial silicone elastomers.

Further long-term in-vitro and clinical studies are recommended to evaluate aging behavior, color stability, biocompatibility, and long-term functional performance before routine clinical application.

Declaration by Authors

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