Frontiers in Dentistry

Effect of Disinfection on Tensile Strength and Rupture Elongation of Maxillofacial Silicone Reinforced with Nano-Filler Particles

Suji Daviasigamani, Ahila Singaravel Chidambaranathan*, Muthukumar Balasubramanium

Department of Prosthodontics. SRM Dental College, Ramapuram, SRM University, Chennai, India

Article Info

Article type:
Original Article

Article History:
Received: 02 Aug 2023
Accepted: 01 Feb 2024
Published: 27 Jul 2024

**** Corresponding author:***

Department of Prosthodontics, SRM Dental College, Ramapuram, SRM University, Chennai, India

Email: ahilasc@yahoo.co.in

ABSTRACT

Objectives: Compare the tensile strength and rupture elongation of room temperature vulcanizing silicone (RTV), heat temperature vulcanizing silicone (HTV) and 3% SiO_2 reinforced RTV and HTV following disinfection with various agents.

Materials and Methods: According to ASTM D412, 384 samples were fabricated using HTV, RTV, RTV and HTV reinforced with 3% SiO_2 nanoparticles. The control group received no disinfection treatment, while the other samples were disinfected for 10 minutes using neutral soap, 4% chlorhexidine, and ozone water, three times a day for 60 days. Additionally, accelerated aging was carried out for 252,504,1008 hours. Tensile strength and rupture elongation were assessed using a universal testing machine at 500 mm/min speed, and the mean values were analyzed using two-way ANOVA and Tukey HSD test ($P<0.05$).

Results: The mean value of tensile strength of RTV (2.96 ± 0.41), 3%SiO_2 RTV (3.26 ±0.33), HTV (3.30 ±0.36),3% SiO_2 HTV (4.07 ±0.85) MPa which was statistically significant for control, neutral soap and 4% chlorhexidine at 252,504 ,1008 hours of aging. ($P<0.05$). The percentage of elongation of RTV (545 ±29.2),3%SiO_2 RTV (617 ±30.5), HTV (735 ±48.7),3% SiO_2 HTV (801 ±55.7) which was statically significant for control, neutral soap, 4% chlorhexidine and Ozone water for 252, 504 ,1008 hours of aging. ($P<0.05$).

Conclusion: The HTV silicone showed more tensile strength and rupture elongation compared to HTV, RTV and RTV silicones reinforced with 3% SiO_2 nanoparticles. Ozone water disinfection had least effect on tensile strength and rupture elongation of maxillo-facial silicone compared to other disinfectant.

Keywords: Aging; Disinfection; Silicone; Tensile Strength; Ozone

➢ **Cite this article as:** Daviasigamani S, Singaravel Chidambaranathan A, Balasubramanium M. Effect of Disinfection on Tensile Strength and Rupture Elongation of Maxillofacial Silicone Reinforced with Nano-Filler Particles. *Front Dent.* 2024:21:28.

INTRODUCTION

Maxillofacial defects occur due to trauma, surgery, infectious diseases, congenital anomalies and burns [1]. The restoration of extraoral defects can be achieved through surgical, prosthetic, or a combination of both approaches. Commonly employed materials for crafting maxillofacial prostheses include polymethylmethacrylate (PMMA) resins and copolymers, vinyl resins, polyurethane polymers, and maxillofacial silicones [2,3].

The most challenging problems of extra-oral maxillofacial prostheses are deterioration of physical properties and discoloration. The principal source of discoloration is ultraviolet radiation, air pollution, temperature alteration and precipitation of microscopic residues in porosities of the surface of the material. The surface texture of the material should be equal to that of human skin to produce a life like appearance [4]. Silicone is the currently used material for rehabilitation of maxillofacial defect. The major drawbacks of silicone materials are deterioration of physical properties and discoloration in the environment [5]. Hence the extra-oral prostheses should be steady, long standing, soft and pliable. High percentage of elongation and tear strength produced the most desirable prosthesis material.

Nano dental materials revolutionized material sciences in dentistry [6]. Titanium dioxide, silaned silica, fumed silica, zinc oxide, cerium oxide, polyhedral silsesquioxane, magnesium silicate nanoparticles and tulle were used as reinforcement material for polymers like PMMA resin and maxillofacial silicone. The literature showed that nanomaterials enhanced the mechanical properties and color stability of maxillofacial silicones [7-9].

The shortfall of maxillofacial silicone is narrow durability of the resulting prostheses. Hence enhancing the tensile strength and tear strength of maxillo-facial silicone lead to long lasting prosthesis [10]. Silicon dioxide nanoparticles (SiO_2) have been widely utilized for biomedical applications due to its biocompatibility. SiO_2 nanoparticles are characterized by small size, large interface area, active, and potential interaction with organic polymers. So, they can improve the properties of polymers and provide resistance to environmental stress and the amount should be optimum to prevent agglomeration of maxillofacial silicone while manipulation [11].

Ozone water was used by Dr Edwin Parr (1920) for disinfection in dentistry. It was applied to purify water, highly effective in killing bacteria bacteria, fungi, viruses, and parasites in lower concentration [12]. There were no relevant studies on the effect of ozone water on the properties of maxillofacial silicone with SiO_2 nanoparticles. Hence the current investigation was performed to evaluate and compare the tensile strength and rupture elongation of Room Temperature Vulcanizing (RTV) silicone, Heat Temperature Vulcanizing (HTV) silicone, and 3% SiO2-reinforced variations of both RTV and HTV following disinfection with neutral soap, 4% chlorhexidine, and ozone water. The null hypothesis was that there will not be any changes in tensile strength and elongation after disinfection and accelerated aging.

MATERIALS AND METHOD

According to ASTM D412 [13], a dumb-bell-shaped stainless-steel split metal mold was fabricated with a diameter of 115mm length, 25mm height and 3mm thickness. (Figure.1) The center of the dumb-bell was 33mm, 6mm, and 3mm in length, height, and thickness, respectively. The samples were fabricated in four groups using RTV silicone (M511 Technovent, P&O internationals, Haryana, India) and HTV silicone (Copsil T-30 TN Resin, P&O internationals, Haryana, India). Additionally, the samples were reinforced with 3% silicone dioxide nanoparticles while being manipulated. Six samples were fabricated in each group.

Control sample fabrication

According to the manufacture's instruction, the RTV maxillofacial silicone base and catalyst were mixed (10g of silicone elastomer to1g catalyst) on a glass plate for 30 minutes with stainless steel spatula to obtain a homogenous mix and it was placed in a vacuum chamber for 20 minutes to remove air bubbles. The mixture was then poured into a stainless steel split coated with a separating media and allowed to dry for 30 minutes. The silicone materials were allowed to polymerize at room temperature (23±2°C) for 24 hours, after which the moulds were carefully separated, and the samples were retrieved and the flash was trimmed out with a sharp scalpel. The HTV silicone was mixed in the ratio of 1:1 on a glass plate with a stainless steel spatula to obtain a homogenous mixture for 30 minutes and it was placed in the vacuum chamber for 20 minutes to remove air bubbles. The mixture was then poured into the stainless steel split mould and allowed to polymerize at 90° for 1h in a hot air oven (Servo Enterprisess, Chennai, India).

Experimental sample fabrication

According to the manufacturer's instruction, 10g of RTV maxillofacial silicone base (Technovent M511 RTV silicone, P&O Internationals, Haryana, India) and 1g of catalyst were measured using a digital analytical scale. Initially, SiO_2 nanoparticles (30 to 50nm) (Aerosol, VV Pharm, Mumbai, India) were added to the pre-weighed catalyst of the maxillofacial silicone and mixed for 10 minutes. Subsequently, the pre-weighed base was added and mixed for an additional 30 minutes on a clean glass plate using a stainless steel spatula to achieve a homogeneous mixture. The resulting mixture was then placed in a vacuum chamber for 20 minutes to remove any air bubbles, ensuring an air bubble-free sample. The mixture was poured into a stainless-steel split mold coated with a separating media, allowed to dry for 30 minutes, and polymerized at room temperature (23±2∘C) for 24 hours. Excess materials were trimmed using a scalpel. The HTV silicone (Copsil T-30 TN resin, P&O Internationals, Haryana, India) catalyst and base were mixed in a 1:1 ratio. Initially, SiO_2 nanoparticles were added to the pre-weighed HTV silicone elastomer base and stirred for 30 minutes. Subsequently, the catalyst was added and mixed for an additional 20 minutes on a clean glass plate using a stainless steel spatula to achieve a homogeneous blend. The mixture was then placed in a vacuum chamber for 30 minutes to ensure the removal of air bubbles. The resulting bubble-free sample was poured into a stainless-steel split mold and left to polymerize at 90∘ degrees for 1 hour in a hot air oven. Finally, excess material was trimmed using a scalpel.

Disinfection procedure and aging process

The maxillofacial silicone samples underwent a disinfection process involving neutral soap (Johnson; Chennai), 4% chlorhexidine (Microshield; Chennai), and ozone water for 10 minutes [14]. Subsequently, the samples were rinsed with water for 10s. This disinfection procedure was repeated three times a day for 60 days. All samples were stored in a light-proof black box under controlled conditions of temperature (23±2ºC) and relative humidity (50±10%) following disinfection. The control group included samples without any disinfection treatment, while separate groups were designated for neutral soap, 4% chlorhexidine, and ozone water treatments.

To replicate the natural environmental conditions (sunlight and moisture), the samples underwent accelerated aging. Placed in an aging chamber with 100% humidity, the aging process extended for 12h. UV light irradiation occurred at a temperature of 60±3°C during the initial eight hours, followed by a continuation of the condensation process at a temperature of 45±3°C without light for the remaining 4h [15].

Tensile strength and elongation test

The thickness of the samples were measured at three separate positions using a digital vernier caliper (Yamato, Madurai,Tamil Nadu).Then the samples were kept in a computer controlled universal testing machine (Schimadzu, Europe) at a constant rate of 500 mm/min cross-head speed. The tensile strength (MPa) was calculated using the following formula TS=F/A (Force required to break (F); A is the cross-sectional area where TS is the tensile strength (MPa) [16].

The original length of the samples were measured before testing using a digital vernier caliper by placing benchmarks on the dumb-bell shaped specimen 25mm apart and equidistant from the center and perpendicular to the long axis. The supplemental distance between the benchmarks of the samples at break were calculated digitally by the computer software. According to ISO (2017), the percentage of elongation was calculated at the time of measuring tensile strength (before failure) using the formula:

$$E = 100\ \frac{(LB - LO)}{LO}$$

Where E is the percentage elongation at break, LO is the original length and LB is the length of the sample while breaking [16].

Statistical Analysis

The results were statistically analyzed using SPSS windows 17 th version (IBM; New York, United State). The obtained tensile strength and rupture elongation values were statistically analyzed using two-way ANOVA at 95% confidence interval. The tensile strength and rupture elongation of maxillofacial silicone materials after disinfection and accelerated aging were considered as significant when the P-value was <0.05.

RESULTS

Comparing the mean value of tensile strength after sixty days of disinfection with neutral soap, 4% chlorhexidine and ozone water and accelerated aging for 252,504,1008 hours, HTV silicone reinforced with 3% SiO_2 showed the highest tensile strength (4.07±0.85) followed by HTV silicone (3.30 ±0.36) (Figure 2) and the highest mean value of elongation was obtained with HTV silicone reinforced with 3% SiO_2 (801 ±55.7) followed by HTV silicone (735 ±48.7) (Figure 3). Ozone water

Fig. 1. Maxillofacial silicone sample

disinfection showed the least effect on tensile strength and rupture elongation. Also, the aging procedure did not have any effect on tensile strength but affected the elongation of the materials (Figure 2).

Comparison of tensile strength of RTV, HTV and 3% SiO_2 reinforced RTV and 3% SiO_2 reinforced HTV silicone after 60 days of disinfection and accelerated aging for 252,504,1008 hours was done using two-way ANOVA. Disinfection had a non-significant effect on tensile strength. (Table.1) Multiple group comparison was done using Tukey HSD test in which the tensile strength was statically significant for control, neutral soap and 4% chlorhexidine at 252,504 ,1008 hours of aging ($P<0.05$). Ozone water showed non-significant effect on tensile strength ($P>0.05$) (Table.2).

Comparison of rupture elongation of RTV, HTV and 3% SiO_2 reinforced RTV and 3% SiO_2 reinforced HTV after 60 days of disinfection and 252,504 ,1008 hours of aging was done using two-way ANOVA. Disinfection significantly affected rupture elongation of all silicone materials (Table.3). Multiple group comparison was done using Tukey HSD test which showed statically significant rupture elongation for control, neutral soap, 4% chlorhexidine and Ozone water for 252,504 ,1008 hours of aging ($P <0.05$) where Ozone water showed significant effect compared with control and chlorhexidine 252,504,1000 hours of aging. ($P<0.05$). (Table.4)

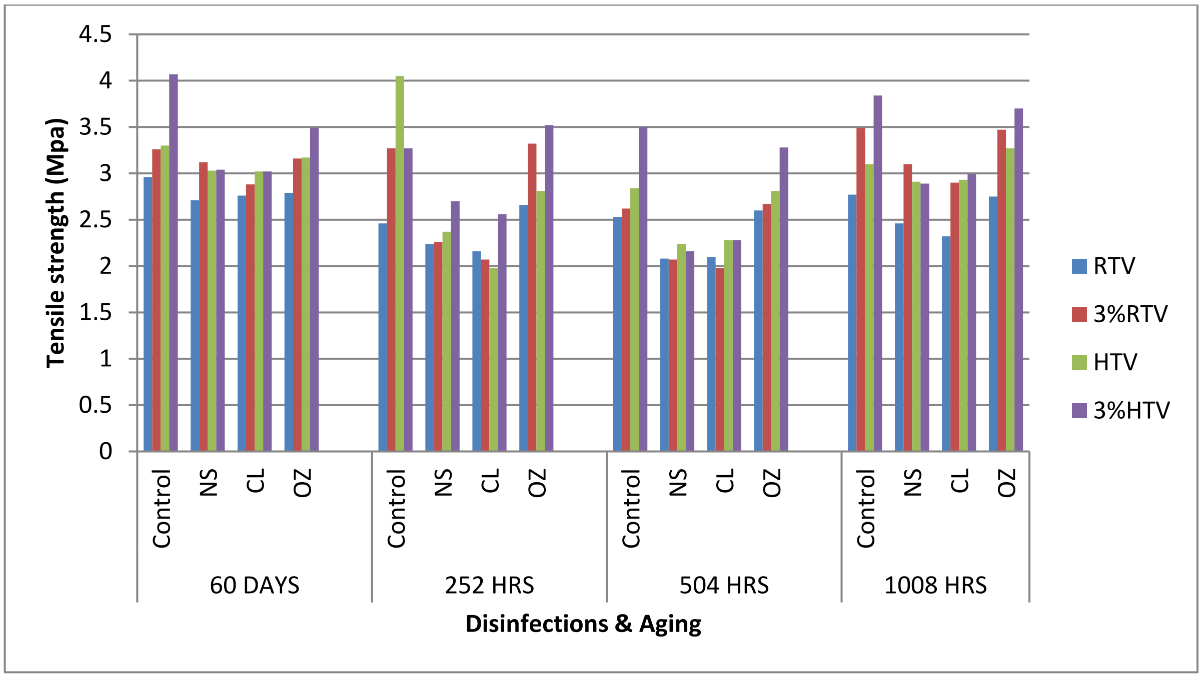

Fig. 2. Comparison of mean value of tensile strength between maxillofacial silicone materials after disinfection for 60 days and accelerated aging for 252, 504, and 1008 hours

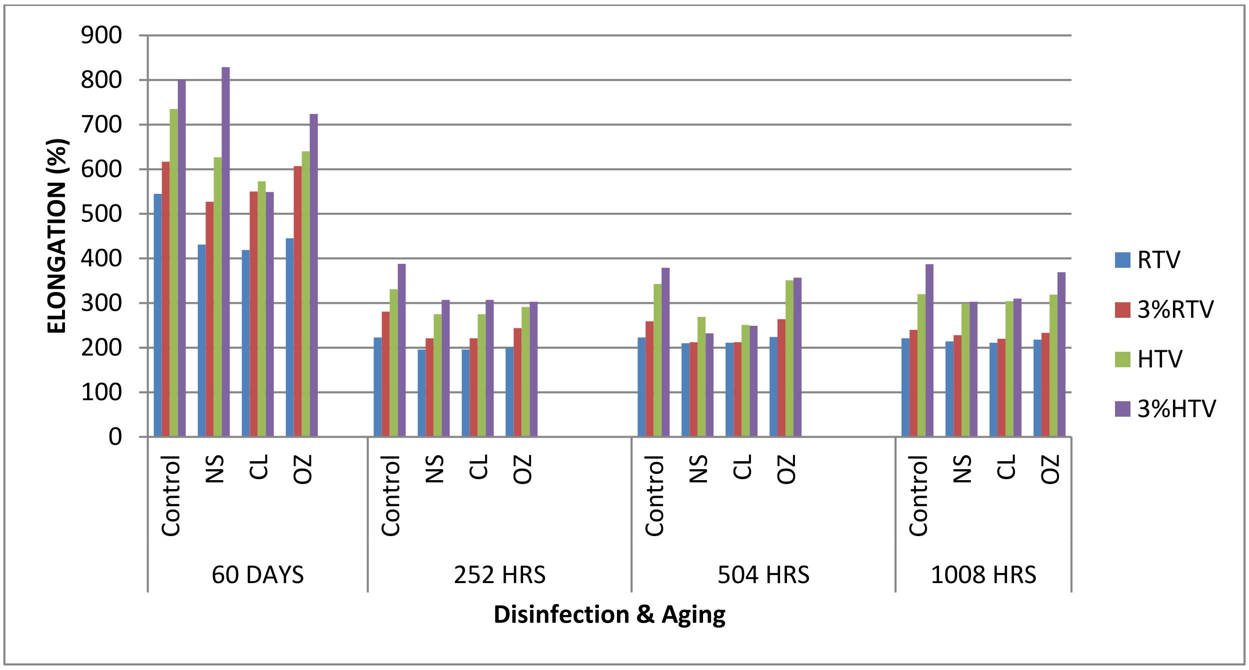

Fig. 3. Comparison of mean value of rupture elongation between maxillofacial silicone materials after disinfection for 60 days and accelerated aging for 252, 504, and 1008 hours

Table 1. Two-way Analysis of Variance for comparison of tensile strength among the studied materials

Source	Type III sum of squares	df	Mean square	F	P
Corrected model	9.66	15	0.64	3.7	<0.0001
Intercept	932.44	1	932.44	5361.93	<0.0001
Materials	4.31	3	1.43	8.27	<0.0001
Group	3.29	3	1.09	6.31	0.001
Materials group	2.04	9	0.22	1.3	0.246
Error	13.91	80	0.17		
Total	956.01	96			
Corrected Total	23.57	95			

Table 2. Tukey HSD test for comparison of tensile strength among the disinfection solutions

(I) Group	(J) Group	MD (I-J)	SE	P	95% CI	
					LB	UB
Control group	Neutral soap	0.41	0.12	0.004	0.1	0.73
	4% CHX	0.47	0.12	0.001	0.16	0.79
	Ozone water	0.24	0.12	0.188	-0.07	0.55
Neutral soap	Control group	-0.41	0.12	0.004	-0.73	-0.1
	4% CHX	0.05	0.12	0.965	-0.25	0.37
	Ozone water	-0.17	0.12	0.468	-0.49	0.14
4% CHX	Control group	-0.47	0.12	0.001	-0.79	-0.16
	Neutral soap	-0.05	0.12	0.965	-0.37	0.25
	Ozone water	-0.23	0.12	0.225	-0.54	0.08
Ozone Water	Control Group	-0.24	0.12	0.188	-0.55	0.07
	Neutral Soap	0.17	0.12	0.468	-0.14	0.49
	4% CHX	0.23	0.12	0.225	-0.08	0.54

CHX: chlorhexidine; MD: mean difference; SE: standard error; CI: confidence interval; LB: lower bound; UB: upper bound

Table 3. Two-way Analysis of variance for comparing rupture elongation among the studied materials

Source	Type III sum of squares	df	Mean square	F	P
Corrected model	1.368E6	15	91203.75	47.79	<0.0001
Intercept	3.474E7	1	3.474E7	18208.33	<0.0001
Materials	908118.91	3	302706.3	158.64	<0.0001
Group	275766.83	3	91922.27	48.17	<0.0001
Materials group	184170.58	9	20463.39	10.72	<0.0001
Error	152645	80	1908.06		
Total	3.626E7	96			
Corrected total	1520701.33	95			

Table 4. Tukey HSD test for comparison of rupture elongation among disinfection solutions

(I) Group	(J) Group	MD (I-J)	SE	P	95% CI	
					LB	UB
Control	Neutral soap	70.75	12.61	<0.0001	37.66	103.84
	4% CHX	151.42	12.61	<0.0001	118.33	184.5
	Ozone water	70.33	12.61	<0.0001	37.25	103.42
Neutral soap	Control group	-70.75	12.61	<0.0001	-103.84	-37.66
	4% CHX	80.67	12.61	<0.0001	47.58	113.75
	Ozone water	-0.42	12.61	1	-33.5	32.67
4% CHX	Control group	-151.42	12.61	<0.0001	-184.5	-118.33
	Neutral soap	-80.67	12.61	<0.0001	-113.75	-47.58
	Ozone water	-81.08	12.61	<0.0001	-114.17	-48
Ozone Water	Control group	-70.33	12.61	<0.0001	-103.42	-37.25
	Neutral soap	0.42	12.61	1	-32.67	33.5
	4% CHX	81.08	12.61	<0.0001	48	114.17

CHX: chlorhexidine; MD: mean difference; SE: standard error; CI: confidence interval; LB: lower bound; UB: upper bound

DISCUSSION

Silicon dioxide nanoparticles are widely employed in biomedical research owing to their excellent biocompatibility. These nanoparticles have found applications as additives in rubber, plastics, and construction materials, providing stability and non-toxicity. Their stability and non-toxic nature make them suitable for use in drug delivery and theragnostic. Consequently, they were chosen as reinforcement material in the context of this study [11].

Chemical disinfection may alter the properties of maxillofacial silicone. Hence it is important to investigate the mechanical properties of maxillofacial silicone materials after disinfection [17]. Various disinfectants like neutral soap, sodium hypochlorite solution, 4% chlorhexidine, efferdent-tablet, plant extract, commercial disinfecting solution are available to disinfect the maxillofacial silicone materials [18].

Recent literature showed that ozone water has antimicrobial, disinfectant, biocompatibility and healing properties, hence its use has been proposed in the field of dentistry for various treatments [19]. Ozone application in dentistry is widely used for the treatment of incipient caries, root canal treatment, periodontal pockets, incomplete wound healing like ulcerations and herpetic lesions, discolored tooth, periimplantitis, denture cleaning and decontamination of tooth brush. Hence ozone water was selected for disinfection of maxillofacial silicone materials [12].

The aging process is crucial for assessing how a material responds to natural environmental conditions, replicating atmospheric factors such as radiation, humidity, and heat in a laboratory setting. The alterations in optical and mechanical properties of silicones are attributed to the photo-oxidation caused by ultraviolet radiation. Therefore, the aging process serves as a means to determine whether the material can withstand environmental conditions without compromising its mechanical properties [20]. Previous studies have indicated that silicone prostheses have a shelf life of one year. Hence, this study was undertaken to evaluate the tensile strength and rupture elongation of maxillofacial silicone materials reinforced with 3% SiO_2 nanoparticles after disinfection and subjected to 252,504,1008 hours of accelerated aging.

The present study results showed the tensile strength and rupture elongation of RTV and HTV silicone values similar to the previous study [11,20], hence, it proved that 3% of silicone dioxide nanoparticles had improved the tensile strength and rupture elongation after disinfected for 60 days with neutral soap ,4% chlorhexidine and ozone water and the ozone water showed least effect on tensile strength and rupture elongation after accelerated aging period of 252,504,1008 hours.

The tensile strength and percentage of elongation of HTV silicones reinforced with 3% SiO_2 nanoparticles was higher after disinfection and accelerated aging compared to controls. Also, our results showed that ozone water had the least effect on tensile strength and percentage of elongation of maxillofacial silicones compared to neutral soap and 4% chlorhexidine. Therefore, this study rejected the null hypothesis.

The present study's findings corroborate previous research, confirming that nanoparticle-reinforced maxillofacial silicone exhibits increased tensile strength and percentage of elongation after disinfection. This is attributed to the small size of SiO_2 nanoparticles, providing a larger surface area, heightened activity, and robust interconnection with the organic polymer. Thus, there is a trust that nanoparticles enhance the mechanical, physical, and optical properties of the organic polymer, escalating its resistance to crack formation influenced by environmental stress [21]. Nano-fillers demonstrate superior mechanical properties compared to micro-filler particles in maxillofacial silicone, indicating their ability to withstand mechanical degradation [22,23].

This study has certain limitations. Firstly, the accelerated aging of maxillofacial silicone was carried out using a UV chamber, introducing a potential disparity between the photo-oxidative impact created by artificial aging and the effects of natural aging, which can be influenced by varying environmental conditions due to climate differences. Additionally, the manual manipulation of the maxillofacial silicone material raises concerns about achieving a uniformly mixed composition. The incorporation of 3% SiO_2 nanoparticles into HTV maxillofacial silicone resulted in enhanced tensile strength and rupture elongation, indicative of improved flexibility in the prosthesis. This enhancement suggests a potential increase in the average lifespan of maxillofacial silicone materials. Consequently, 3% SiO_2 nanoparticle-reinforced HTV silicone holds promise for the fabrication of extraoral prostheses with an extended shelf life.

CONCLUSION

The HTV silicone reinforced with 3% SiO_2 nanoparticles exhibited enhanced tensile strength following 60 days of disinfection and accelerated aging for 252,504,1008 hours. Ozone water disinfection had the least impact on tensile strength and percentage of elongation compared to neutral soap and 4% chlorhexidine disinfection over the same period. Consequently, ozone water emerges as a viable recommendation for the disinfection of maxillofacial prostheses

CONFLICT OF INTEREST STATEMENT

None declared.

REFERENCES

1. Alqutaibi AY. Materials of facial prosthesis: History and advance. Int J Contemp Dent Med Rev. 2015;2015:4.

2. Begum Z, Kola MZ, Joshi P. Analysis of the properties of commercially available silicone elastomers for maxillofacial prostheses. Int J Contemp Dent. 2011 Jul 1;2(4).

3. Maller U, Karthik K S, Maller S. Maxillofacial prosthetic material-past and present trend. J Indian Acad Dental Specialist Researchers. 2010;2:25-30.

4. Guiotti AM, Goiato MC, dos Santos DM. Evaluation of the Shore A hardness of silicone for facial prosthesis as to the effect of storage period and chemical disinfection. J Craniofac Surg. 2010 Mar;21(2):323-7.

5. Al-Dharrab AA, Tayel SB, Abodaya MH. The effect of different storage conditions on the physical properties of pigmented medical grade I silicone maxillofacial material. ISRN Dent. 2013 Mar 28;2013:582051.
6. Eleni PN, Krokida MK, Polyzois GL, Gettleman L. Effect of different disinfecting procedures on the hardness and color stability of two maxillofacial elastomers over time. J Appl Oral Sci. 2013;21(3):278-83.
7. Khurshid Z, Zafar M, Qasim S, Shahab S, Naseem M, AbuReqaiba A. Advances in Nanotechnology for Restorative Dentistry. Materials (Basel). 2015 Feb 16;8(2):717-31.
8. Mohammad SA, Wee AG, Rumsey DJ, Schricker SR. Maxillofacial materials reinforced with various concentrations of polyhedral silsesquioxanes. J Dent Biomech. 2010 Jul 20;2010:701845.
9. Orellana RV, Coto NP, Medeiros IS, Dias RB. Evaluation of the mechanical properties of acetic-cure silicone with the addition of magnesium silicate. Acta Scientiarum. Health Sciences. 2015;37(1):85-88.
10. Cevik P, Polat S, Duman AN. Effects of the addition of titanium dioxide and silaned silica nanoparticles on the color stability of a maxillofacial silicone elastomer submitted to artificial aging. Cumhur Dent J. 2016;19: 9–15.
11. 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;2014:750398.
12. Rubin M. The History of Ozone; the Schonbein Period, 1839-1868. Bull. Hist. Chem. 2001;26(1):40-50.
13. ASTM. D412-16, Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers-Tension, ASTM International, West Conshohocken, PA, 2016.
14. Goiato MC, Pesqueira AA, dos Santos DM, Zavanelli AC, Ribeiro Pdo P. Color stability comparison of silicone facial prostheses following disinfection. J Prosthodont. 2009 Apr;18(3):242-4.
15. ASTM G. Standard practice for operating fluorescent ultraviolet (UV) lamp apparatus for exposure of nonmetallic materials. ASTM International. 2016:1-1.
16. ISO B. 37: 2017: Rubber, vulcanized or thermoplastic-Determination of tensile stress-strain properties. British Standards Institution (BSI), London. 2017
17. Faoagali JL, George N, Fong J, Davy J, Dowser M. Comparison of the antibacterial efficacy of 4% chlorhexidine gluconate and 1% triclosan handwash products in an acute clinical ward. Am J Infect Control. 1999 Aug;27(4):320-6.
18. Eleni PN, Krokida MK, Polyzois GL, Gettleman L. Dynamic mechanical thermal analysis of maxillofacial prosthetic elastomers: the effect of different disinfecting aging procedures. J Craniofac Surg. 2014 May;25(3):e251-5
19. Gopalakrishnan S, Parthiban S. Ozone-a new revolution in dentistry. J Bio Innov. 2012 Nov;1(3):58-69.
20. Hatamleh MM, Polyzois GL, Silikas N, Watts DC. Effect of extraoral aging conditions on mechanical properties of maxillofacial silicone elastomer. J Prosthodont. 2011 Aug;20(6):439-46.
21. Akash RN, Guttal SS. Effect of Incorporation of Nano-Oxides on Color Stability of Maxillofacial Silicone Elastomer Subjected to Outdoor Weathering. J Prosthodont. 2015 Oct;24(7):569-575.
22. Barman A, Rashid F, Farook TH, Jamayet NB, Dudley J, Yhaya MFB.et al. The Influence of Filler Particles on the Mechanical Properties of Maxillofacial Prosthetic Silicone Elastomers: A Systematic Review and Meta-Analysis. Polymers (Basel). 2020 Jul 12;12(7):1536.
23. Sonnahalli NK, Chowdhary R. Effect of nanoparticles on color stability and mechanical and biological properties of maxillofacial silicone elastomer: A systematic review. J Indian Prosthodont Soc. 2020 Jul-Sep;20(3):244-254.