Effect of calcium carbonate nanoparticles on the bonding strength of maxillofacial silicone to acrylic substrate

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Abstract

Background: The clinical life of a maxillofacial prosthesis averages about six months before it needs to be re-fabricated. Most of maxillofacial prosthesis attached to the acrylic resin via adhesive primers detached and have to be re-attached every few months.

Materials and Methods: This in vitro study established to evaluate the effect of adding calcium carbonate nanoparticles at different concentrations on the bonding strength of maxillofacial silicone elastomer to the acrylic resin, before and after accelerated aging.

Method: Seventy samples were prepared, ten samples per each group. Each silicone sample sandwiched between two strips of acrylic resin via A-330-G adhesive primer. From each group five samples were undergoing accelerated aging. All samples were tested for shear bond strength by using Instron testing machine.

Results: Calcium carbonate nanoparticles have a significant effect on the shear bond strength of maxillofacial silicone to the acrylic resin and the groups that contain the lowest concentrations of calcium carbonate nanoparticles showed the most significant changes.

Conclusion: it CaCO3 nanoparticles in trace amount can improve the shear bond strength of maxillofacial silicone elastomer to the acrylic resin after subjecting to accelerated aging.

Keywords: *Maxillofacial silicone elastomers; calcium carbonate nanoparticles; A-330-G adhesive primer; acrylic resin; shear bond strength.*

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Introduction:

Maxillofacial prostheses are constructed to restore function and natural appearance of the face and associated structures of facially disfigured patients. Silicone elastomers have been widely used in fabricating these prostheses, as they are biocompatible, elastic, and can be pigmented to simulate skin tone (1,2). In maxillofacial silicone prostheses, silicone elastomers are conventionally bonded to a retentive acrylic base plate, which holds the retentive magnets or clips (3,4), or a cast titanium plate (5,6). Alternatively, the base plate can be attached to a polyurethane layer6 when the prosthesis is adhesively retained (7).

Extra-oral facial prostheses used in conjunction with implants require a retentive matrix to hold the bar clips or magnets. The retentive matrix is commonly made from acrylic resin (i.e. heat-polymerizing, auto-polymerizing, or light-cured materials) to which the facial silicone elastomer is attached. Hence, sufficient bond strength is vital to ensure serviceable and functional prosthesis. As several potential solutions have been introduced to overcome problems associated with silicone elastomer; delaminating of silicone away from the retentive matrix is still a persisting problem (8).

The interfacial bond strength between different types of silicone facial elastomers and denture resins was evaluated by Polyzois and Frangou (9). The tested facial materials were Cosmesil, SR 3/60, SR 3/60 Quick, and Triad were included in the study as a denture resins group. The overlap joint model was used to evaluate the bond strength, and the samples were placed in tension until failure. The bonding surfaces were treated with a primer. The results showed that the tensile bond strength was affected by the type of silicone elastomer and denture resin. The shear bond strength of Molloplast-B with different acrylic surfaces was evaluated; smooth, rough and Stick net fibre-reinforced interfaces. Bond failures were categorized adhesive, cohesive and mixed failures. It was found that there was a statistically significant difference between group 3 and group 1 only.

Modes of failure were different; mixed and cohesive only exhibited. StickTech Net fibre-reinforced surfaces exhibited stronger bond to Molloplast-B over non-reinforced interfaces (10). Two years later also Hatamleh and Watts evaluated the effect of three different primers (611, A304, A330-G) on shear and peel bond strengths between three maxillofacial silicone elastomers (TechSil S25, Cosmesil M511, Cosmesil Z004) and an acrylic resin after accelerated daylight-aging. The results showed that in the peel bond test, at both baseline and after aging, there was a significant influence of primers and silicones on bond strength and a strong interaction was also found between primers and silicones. While In the shear bond test, there was only a significant influence of silicones on shear-bond strength, whereas primers did not affect it, and no interaction between primers and silicones was found (8).

The effect of 3 silicone primers (G611 platinum primer, A-330 Gold Platinum primer, and cyanoacrylates resin) and 3 surface characterization of acrylic resin surface (retentive holes with 1.5 mm in diameter and 0.5 mm deep, retentive beads of 0.6 mm diameter and the third type which was plain without any characterization) on bond strength between silicone elastomer and acrylic resin was evaluated. The results revealed that there were significant differences in the bond strength with maximum bond strength was seen for samples in which A-330G primer was used followed by G611 primer. The control group showed the minimum bond strength. Surface characterization of retentive holes increased the bond strength considerably as compared to retentive beads and samples without any surface characterization (11).

Nanostructures constitute a bridge between molecules and infinite bulk systems. The physical and chemical properties of nanostructures are distinctly different from those of a single atom (molecule) and bulk matter with the same chemical composition. These differences between nanomaterials and the molecular and condensed-phase materials pertain to the spatial structures and shapes, phase changes, energetics, electronic structure, chemical reactivity, and catalytic properties of large, finite systems, and their assemblies. Some of the important issues in nanoscience relate to size effects, shape phenomena, quantum confinement, and response to external electric and optical excitations of individual and coupled finite systems (12).

Materials and methods:

Calcium carbonate nanoparticles added to silicone elastomer matrix at (0, 0.5, 1, 1.5, 2, 2.5, 3% by weight), the calcium carbonate loaded silicone mixed in vacuum mixer for 15minutes to ensure homogenous air bubble free mix, then the mix left in the mixing jar for 5 minutes to allow settling of the mixed silicone. The mix then poured onto a glass slab with dimensions 50X20cm, lastly another glass slab with the same dimensions placed over the first slab with a small glass strip of 0.5cm between them; the glass strip allows a uniform thickness of the whole silicone mix that sandwiched between the glass slabs. Finally, the poured silicone left for 24hour at 25°C to cure according to manufacturer instruction. After curing of the silicone elastomer strips of silicone were cut off with a dimension of 10 x 5 x 0.5 cm.

Ten silicone strips were prepared per each calcium carbonate loading, five of the silicone samples undergo accelerated aging according to ASTM G155-05a cycle 2. Strips of hot cure acrylic resin samples were prepared according to the manufacturer instruction, the dimensions of the sample was 12 x 5 x 0.2 cm.

The ten silicone samples (five samples undergo accelerated aging and the other five control samples (non-aged)) then attached to two acrylic resin samples by A330G adhesive primer, as shown in figure 1.

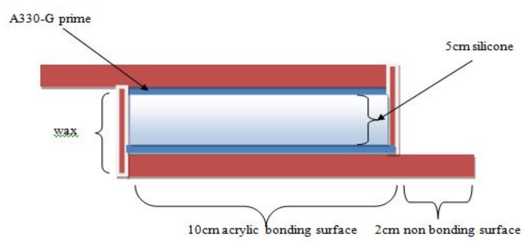

Figure1. Bonding strebgth sample

The acrylic samples were wrapped with acetone to removing any debris that might attach to it. Then adhesive primer was painted to the acrylic samples, leaving 2cm uncoated. Lastly, the silicone strips attached to the painted surface of the acrylic. The prepared samples left 24 hours to ensure complete bonding between the acrylic samples and the silicone sample, according to manufacturer instructions.

The bonding samples attached to instron (PTLI, U.S.A) testing machine at the free ends (2cm) by using special grips then pulled at a rate of 50mm/minute as shown in figure 2. The force that causes detachment of the sample recorded and analyzed.

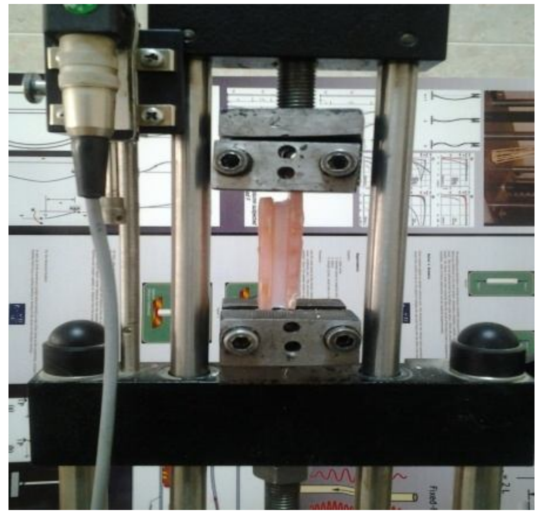

Figure2. Sample attached to instron machine

Results:

The data obtained were analyzed by ANOVA test, the results for bonding strength before accelerated aging showed that there was no any significant difference between samples of the seven different loading of calcium carbonate nanoparticles, however, the group that contain 0.5% calcium carbonate showed the highest mean value of bonding strength, as shown in Table 1. After accelerated aging, it found that the bonding strength was increased and there was a significant improvement between the different groups of calcium carbonate nanoparticle loadings, as shown in Table 2. Also, it found that the group that contains the least amount of calcium carbonate nanoparticles showed the highest mean of bonding strength. Paired T-test used to compare each sample group before and after accelerated aging. It found that there was a significant difference between the corresponding groups for the low concentrations of calcium carbonate nanoparticles (0.5-2% by weight), while for the higher concentrations it found that there was no any significant improvements in the bonding strength, as shown in Table 3.

Discussion:

Bonding of maxillofacial silicone elastomers to acrylic substrates (polymethyl methacrylate) is a crucial factor that enhances the serviceability of maxillofacial prostheses, not only during placement and removal of the prosthesis but also during mold opening and deflasking procedures (8).

The result of this research showed that there was no any significant difference in bond strength between the controlled group and the reinforced groups.

The possible explanation is that the chemical structure of maxillofacial silicone elastomers (dimethylsiloxane polymers) and PMMA denture base resin is different, exhibiting poor bond characteristics. Hence, primers are provided to increase the bond strength between silicone elastomer and acrylic resin, thereby preventing delamination of silicone and enhancing the longevity of the prosthesis. These primers increase the bond strength by activating the surface of the acrylic via etching and promoting hydrogen bonding and covalent coupling, which subsequently increase the wettability of the PMMA denture base.

The mechanism of the bonding that enhanced by the primer is that adhesive primers have an organic solvent and adhesive agent that react with the functional group of silicone (-OH) and resin materials (13), serving as a chemical intermediate between the silicones and the acrylic substrate, as the hydrophilic and hydrophobic groups on the primers reactive sites react with the functional groups of silicone. At the same time, primers activate the substrate surfaces via etching and promoting hydrogen bonding and covalent coupling, increasing the wettability of the substrate, and impregnating the surface layer with the polymeric ingredients.

It was noticed the primer does not react with the nanofillers, since there is no any chemical reaction nor bonding between the nanofillers and the ingredients of the primer, for this reason, the fillers play no role in the improvement of the bonding strength.

Furthermore, the chemical structure of the silicone elastomer is not changed during the reinforcing procedures as mentioned earlier and the $CaCO_3$ particles change the geometry of the silicone matrix and not it's chemical structure so that the bonding strength will be the effect of the primer only.

It was noticed that after accelerated aging the bonding strength increased, it is likely due to its high hardness and tear strengths of the silicone, as stress generated at the soft/rigid interface during the application of stress is greater for stiffer materials (14). As mentioned earlier the adhesive primers have an organic solvent and adhesive agent that react with the functional group of silicone (-OH) and resin materials and as mentioned earlier the accelerated aging enhance and promotes further crosslinking, i.e. further (-OH) will be formed that allow better bonding strength with the silicone.

Table 1. Mean values, standard deviation and ANOVA p-value of Bonding strength (MPa) of the silicone samples to acrylic samples before accelerated aging

Group	N	Mean	SD	ANOVA p-value
Group A	5	1.89	0.58	.063
Group B	5	2.55	0.36	
Group C	5	2.28	0.44	
Group D	5	2.11	0.19	
Group E	5	1.86	0.30	
Group F	5	2.04	0.19	
Group G	5	2.15	0.20	
Total	35	2.13	0.39	

Table 2. Mean values, standard deviation and ANOVA p-value of Bonding strength (MPa) of the silicone samples to acrylic samples after accelerated aging

Group	N	Mean	SD	ANOVA p-value
Group A	5	1.93	0.60	.017
Group B	5	2.76	0.35	
Group C	5	2.50	0.39	
Group D	5	2.36	0.13	
Group E	5	2.14	0.38	
Group F	5	2.12	0.06	
Group G	5	2.28	0.16	
Total	35	2.30	0.40	

Table 3. Least Significant Difference (LSD) test of bonding strength before and after accelerated aging

Group	N	Mean	MD	SD	P (LSD)	P
group A bonding strength before aging	5	27.4	-0.6	.54	.529	.00
group A bonding strength after aging		28		1.65		
group B bonding strength before aging	5	37	-3	.37	.001	
group B bonding strength after aging		40		1.17		
group C bonding strength before aging	5	33	-3.2	.24	.001	
group C bonding strength after aging		36.2		.47		
group D bonding strength before aging	5	30.6	-3.6	.26	.001	
group D bonding strength after aging		34.2		.81		
group E bonding strength before aging	5	27	-4	.96	.009	
group E bonding strength after aging		31		.24		
group F bonding strength before aging	5	29.6	1.2	3.28	.438	
group F bonding strength after aging		30.8		2.52		
group G bonding strength before aging	5	31.2	-1.8	.41	.152	
group G bonding strength after aging		33		.38		

Conclusion:

Within the limitations of this study, the results show a lack of association between denture hygiene and studied socio-demographic factors, except for gender and education. Nor was there an association between other important oral health behaviors except with overnight removal.

Denture biofilm does not seem to influence stomatitis, but overnight denture wearing does influence it. On the other hand, smoking stimulates traumatic ulcer. Participants surveyed had limited awareness of denture hygiene care. Complete denture wearers need improved guidelines regarding denture use and hygiene care. Dentist participation is, of course, essential to control the local factors triggering stomatitis related to wearing dentures so that the treatment will be successful and the oral health of the elderly patient and their quality of life could be improved.

Further research with larger sample size required studying the effect of improving denture hygiene attitude on denture plaque ratio and the prevalence of denture related lesions.

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