The effect of different surface characterization on bonding strength of maxillofacial silicone elastomer to two different framework materials

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Background and Objective: The objective of the study was to compare the bonding strength between silicone elastomer and two types of framework materials (acrylic resin and metal chrome cobalt) with different surface characterization.

Methods A-2186 silicone elastomer was bonded with A-330-G primer to two group of framework materials (acrylic resin and metal chrome cobalt). Each group was subdivided into 4 different surface characterization (Polished surface as a control, Sandblasted surface by aluminum oxide media 250 micron, Polished surface with retentive holes, Surface with retentive holes and sandblasted by aluminum oxide media 250 micron). The samples were prepared with the dimension of (75x 10x 3 mm). All the test groups were subjected to 1800 peel strength test on Hounsfeild universal testing machine (HT-400). The test was carried out according to the ASTM D-903 specifications. The obtained results were then subjected to statistical analysis using Stat Graph 5.1 and the statistical significance was set at 5% level of significance.

Result The result showed no significant difference between polished acrylic and sandblasted acrylic surface. However, a significant improvement in bonding strength was observed when acrylic surface was grooved with retentive holes (with and without sandblast surface characterization). However, a significant effect was seen when the surface of metal chrome cobalt was sandblasted with aluminum oxide media compared to polished metal. Additionally, grooves also improved the bonding strength. Furthermore, superior effects were seen when the grooves where sandblasted. Lastly, Intergroup comparison showed superior bonding strength between metal chrome cobalt and silicone compared to acrylic resin and silicone for all surface characterization.

Conclusion Within the limitations of the present study, it can be concluded that: There is no significant difference when acrylic surface was sandblasted. However, retentive holes improved the bonding strength between acrylic and silicone. While sandblast improved the bonding strength between metal and silicone elastomer. Lastly, metal bond better to silicone than acrylic resin for all tested groups.

Keywords: Maxillofacial Silicone Elastomer, Acrylic Resin, Metal Chrome Cobalt, Bonding Strength.

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Introduction

Patients who lost part of their face experience a change in social acceptance that greatly affects their psychology and their expectation to return to a normal life.[1] Thus, those patients require replacement with maxillofacial silicone elastomer. Even with recent advancements in prosthetic materials, till now no ideal material is existed.[2] Maxillofacial silicones exhibit objectionable properties that prevent them from being accepted by all clinicians. Basically, the main problem of facial prosthesis is retention in large defect.[3] In the mean time, the ideal silicone prosthesis with enhanced physical and mechanical properties is not existed.[4]

Unfortunately, many of the surgical techniques are extensive and thus leave large defects that compromise not only function and aesthetics, but also retention of the prosthesis.[5] Increased retention improves comfort as well as the confidence in the patients. Thus, retention of silicone to the frameworks plays a major role in the success of facial prosthesis.[6,7] Recently implants are used for retention by attaching the silicone prosthesis through framework.[8] Different materials were used as framework to retain prosthesis such as acrylic resin and metal chrome cobalt.[9,10] Metal and acrylic framework can be used as a bar or plate attached to implants, while the counterpart will be embedded in silicone to attached it later to the acrylic or metal. Furthermore, framework materials also will reinforce silicone material, since silicone alone will easily tear.[11]

However, clinically it is difficult to bond the silicone to the metal and acrylic, and de attachments have been observed between framework materials and silicone. Nevertheless, the silicone may tear or separate from the metal and acrylic when patients remove their prosthesis. Thus bonding are used to improve this problem. However, till now ideal banding is not existed. One of the most common type of bonding solution (A-330-G gold primer) which can be used to chemically enhance the bond strength between both (metal- acrylic) and silicone elastomer. Furthermore, another technique that used to increase surface roughness is the sandblasting with aluminum oxide particles (Al2O3). Craig and Gibbons reported that a roughened surface will improve the adhesive bond. They demonstrated that adhesive values obtained with the roughened surface were approximately double those of the smooth surface. Recently, sandblasting with aluminum oxide particles has been shown to provide a relatively safe and easy mean of roughening the surface of materials. Sandblasting is usually applied to provide surface roughening and making the materials more bondable. Sandblasting procedure involves spraying a stream of aluminum oxide particles against the material surface intended for bonding under high pressure. Sandblasting systems rely on particle abrasion with different particle sizes ranging from 30 to 250 μm. The abrasive process removes loose contaminated layers and the roughened surface provides some degree of mechanical interlocking or 'keying' with the adhesive. The increased roughness also forms a larger surface area for the bond. Moreover, the information on the effect of sandblasting with Al2O3 on bond strength between (acrylic resin /metal) and silicone elastomer is lacking.[12] Therefore, the purpose of this study is to investigate the effect of sandblasting with aluminum oxide particles on peel strength of silicone from different framework materials.

In this study, silicone elastomer A-2186 was bonded with A-330-G primer to two group of framework materials, acrylic resin and metal chrome cobalt. Each group was subdivided into four different surface characterization (Polished surface as a control, Sandblasted surface by aluminum oxide media 250 micron, polished surface with retentive holes, surface with retentive holes and sandblasted by aluminum oxide media 250 micron). Then the peel strength were evaluated.

Methods

The peel strength was evaluated between silicone elastomer and two group of framework materials, acrylic resin and metal chrome cobalt.

Acrylic resin sample preparation The bond strength between silicone elastomer type A-2186 (Factor II Inc., Lakeside, AZ, USA) and chemically polymerized acrylic resin was evaluated. Firstly, the specimens were fabricated from wax with the dimension of 75 mm ×10 mm×3 mm, then they were placed into the plaster (Dental Plaster class-II-Korea) to create a mold for acrylic resin. After wax elimination in boiling water for 5 minute. Chemically cured acrylic resin (powder and liquid, Vertex, Netherlands) was mixed and poured into the mold and allowed to set, afterword samples were finished and polished. Acrylic samples where divided into 4 main groups. First group the acrylic surface where polished and considered as a control (Figure 1, A). The second group acrylic surface where sandblasted by aluminum oxide media 250 micron (Figure 1, B). The sandblasting was done by integrating air compressor with aluminum oxide media 250 micron. the spray gun was used and the abrasive mixture traveled through a nozzle that directs the particles toward the surface of the sample. The compressor exhaled 100 psi of compressed air through an air hose (Toyospray RoHS2 SP-8 8.5x14). The distance between the spray gun and test samples was 3 cm and was carried out for 30 seconds. Sandblasting was done in a closed chamber to prevent contamination of outside air against the surface of the test samples. In the third group retentive holes where made on the surface of acrylic with diameter 1.5 mm and depth of 0.5 mm using a round tungsten carbide bur then polished (Figure 1, C). Forth group, same retentive holes where made on the surface of acrylic then sandblasted by aluminum oxide media 250 micron as described previously (Figure 1, D)

Bonding acrylic resin to silicone elastomer

First the acrylic resin sample was overlapped with another acrylic sample of the same dimension (75 mm×10 mm×3 mm) and the borders were sealed neatly with wax to close the gap between the two acrylic samples. The combined thickness of both the samples was 6 mm. The fused acrylic samples were then placed into a box filled with the first plaster pour covering till the junction of the two acrylic samples. Then the plaster was allowed to set and later petroleum jelly was applied as separate medium (Acropars, Iran LBF). Later, the second plaster pour was done and allowed to set. After setting, the two layer of plaster was opened, and the overlapped acrylic blank from the upper member was removed from the mold. The acrylic sample with the required surface characteristic was left in the lower member of the plaster. Next, an adhesive tape was applied to define the area over which the silicone elastomer was to be bonded to the acrylic samples. The tape covered an area of (50 x 10 mm) leaving an uncovered area of (25 x 10 mm) where the silicone had to be bonded to the acrylic sample with the use of bonding agent. (Figure 3, A). Whereas, the upper member acrylic was removed and the space was packed with silicone elastomer that was prepared according to manufacture instruction then the two layers of plaster (upper and lower member) where closed and left for 24 hrs. for silicone curing.

Metal chrome cobalt sample preparation

Metal chrome cobalt was prepared in the laboratory with the same dimensions of acrylic, then the metal samples were placed in the same mold that was used for bonding of silicone to acrylic samples. Similarly, metal samples were subdivided into four different surface characterization. First group the metal surface where polished and considered as a control Figure 2, A. The second group metal surface where sandblasted by aluminum oxide media 250 micro as described previously Figure 2, B.

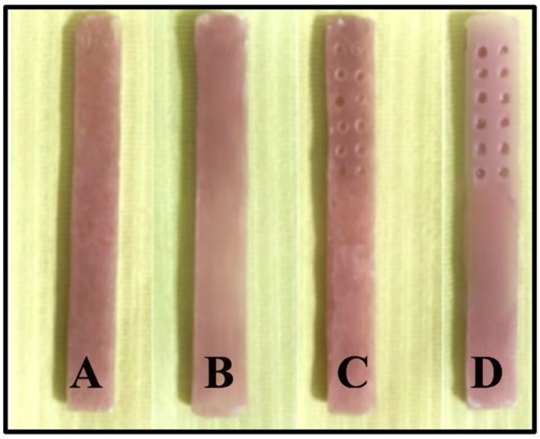

Figure 1. Acrylic resin samples A) Polished acrylic sample (control), B) Acrylic surface sandblasted by aluminum oxide, C) Acrylic surface with retentive holes, D) Acrylic surface with retentive holes and sandblasted by aluminum oxide.

The third group retentive grooves where made on the surface of metal with (1 mm wide and 0.5 deep) then polished (Figure 2, C). Forth group, same retentive grooves where made on the surface of metal then sandblasted by aluminum oxide media 250 micron (Figure 1, D), as described previously.

Bonding metal samples to silicone elastomer

The same procedure that was used to bond (acrylic to silicone), was used to bond (metal to silicone). Similarly, the adhesive tape was applied to define the area over which the silicon elastomer was to be bonded to the metal. The tape covered an area of (25 x10 x 3 mm) and left (50 x10 x 3 mm) free Figure 3, B. Each sample had different type of surface characterization in the area where the silicone had to be bonded to the metal. Bonding agent was applied to metal sample according to the manufacturer's instruction. Then the silicone elastomer was packed and cured according to manufacturer's instructions and left to set in the same manner as described previously.

All the test groups were subjected to a 180 peel strength test on Hounsfeild universal testing machine (HT-400). Figure 3, C The test was carried out according to the ASTM D-903 specifications. In each specimen, the silicone strip was bonded to (acrylic or metal) sample at one end (25 mm 10 mm 3 mm) and left free at the other (50 mm 10 mm 3 mm). The free end of the strip was turned back at 180 so that the hard (acrylic or metal) base was clamped to one side and the soft free silicone strip was gripped by the other clamp. Then force needed to cause bond failures was recorded. Peel strength (N/mm) was determined using the formula Peel strength = F / W (1 + / 2 +1) Where F = maximum force recorded (N); W = Width of samples (mm); = Extension ratio of silicone elastomer (the ratio of stretched to primary length) The results obtained were then subjected to statistical analysis using Stat Graphics Plus Version 5.1. All data are presented as Mean ± S. E were evaluated using ANOVA for parametric data. All statistical analysis used a 95% confidence limit, so that *p* values > 0.05 were not considered statistically significant.

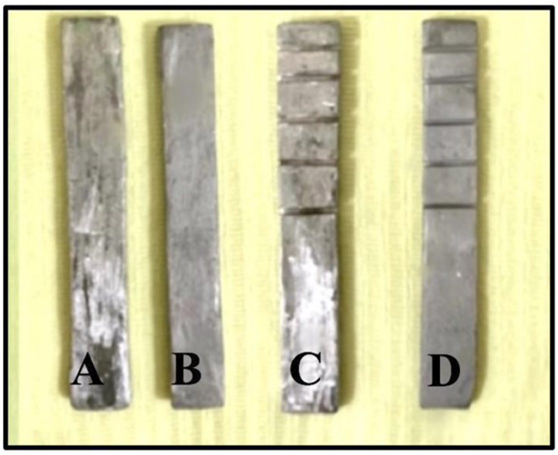

Figure 2. Metal chrome cobalt samples A) Polished metal sample (control), B) Metal surface sandblasted by aluminum oxide, C) Metal surface with retentive grooves, D) Metal surface with retentive grooves and sandblasted by aluminum oxide.

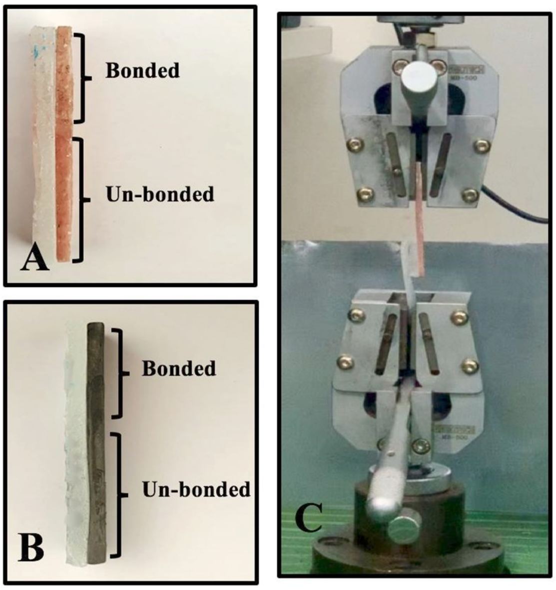

Figure 3. A) Acrylic sample bonded to silicone elastomer. B) Metal sample bonded to silicone elastomer. C) Silicone peeled off from the acrylic resin sample during Peel test using universal testing machine.

Result

Acrylic bonding strength

Bonding strength of acrylic samples and silicone elastomer where investigated by ANOVA, $p < 0.05$, n=10 and all the data were presented as (Mean ± S. E). with Newton (N) Unit. The result showed no statistical difference between control acrylic (0.006 0.001) and sandblasted acrylic (0.006 0.001). However, a significant improvement in bonding strength was observed when retentive holes made on the surface of acrylic (0.018 0.001), and similar results where observed when retentive holes and sandblast where made on the surface of metal (0.012 0.001). In conclusion, the sandblast had no effect on the acrylic-silicone bonding, however, retentive holes had an observable improvement on the acrylic-silicone bonding strength.

The results of metal bonding strength showed that there was a significant difference between control samples (0.012 0.001) and sandblasted metal (0.036 0.003), indicating that sandblast improved bonding strength. Additionally, there was a significant difference between control and grooved metal (0.032 0.002), indicating that grooves improved the bonding strength. Moreover, maximum enhancement was observed when metal surface was sandblasted and grooved (0.049 0.002) compared to other samples. Moreover, significant difference observed when grooved metal (0.032 0.002) was compared with (sandblasted and grooved) metal (0.049 0.002), later had superior results.

Acrylic and metal samples were statistically compared with each other. Data shown in Table 1. The result showed that all tested metal samples were statistically well bonded to silicone when compared with all tested acrylic samples. Which indicating that metal is superior to acrylic and it has greater bonding strength to silicone for all types of surface characterization.

Table 1. Comparing bonding strength between acrylic and metal to silicone. (One-way ANOVA, p< 0.05, n=10). all data (Mean ± S. E). Different letters are statistically different from each other within Colum.

	Control	Sandblasted	Grooved	Sandblasted and grooved
Acrylic	(0.006 ± 0.001) a	(0.006 ± 0.001)a	(0.018 ± 0.001) a	(0.012 ± 0.001) a
Metal	(012 ± 0.001) b	(0.036 ± 0.003)b	(0.032 ± 0.002) b	(0.049 ± 0.002) b

Discussion

Nowadays implant retained extra oral prosthesis is used and the retentive matrix is made either from acrylic (heat or cold cure) or metal (chrome cobalt). The framework matrix should be securely bonded to silicone to retain the prosthesis. The bond of silicone elastomer to the acrylic resin component must be sufficiently tenacious to withstand the substantial forces acting upon the bond interface, not only during placement and removal of the prosthesis, but also during mold opening and deflasking procedures since, this is the weakest link in the restoration.[13,14] However, the chemical structure of maxillo facial silicone elastomers and framework materials (acrylic resin or metal) is different, thus, exhibiting poor bond characteristics. Therefore, primers are provided to increase the bond strength. The A-330-G gold primer increases the bond strength by activating the surfaces via etching and promoting hydrogen bonding and covalent coupling. This lead to increasing in the wettability of the substrate.[15, 16] Basically the maxillofacial prostheses debond when the patients remove the prostheses horizontally. Thus, to measure the bond strength, this type of force is well simulated in the peel test. As it was discussed by other studies.[17-19] For this reason, 180 peel test was used in this study to evaluate the bond strength.

In the present study, the bonding strength between silicone and two types of framework were evaluated (acrylic and chrome) with different surface characteristics. From the result, when bonding strength between acrylic/silicone were compared with bonding strength of sandblasted acrylic/silicone, they showed no statistical difference, this could be due to that sandblast did not change the surface characteristic of the acrylic. However, other studies have demonstrated that the sandblast with aluminum oxide particles reduced the bonding strength.[20,21] Nevertheless, another study revealed that treating the surface of acrylic resin by sandblasting can get the highest bond strength with silicone elastomer,[22] which could be due to fact that they used different particle size which caused increases the surface roughness. While, in present study 250-micron particle size did not improve acrylic surface for bonding. Furthermore, the bonding strength of retentive holes on the surface of acrylic bonded to silicone was improved dramatically. This is in agreement with a study conducted by Chauhan et al. (2018)[23] and Jagger et al. (2002)[24] as they demonstrated that the roughened surface of acrylic improved bond strength with silicone.

This could be explained as that the irregular surface can provide mechanical locking for the silicone material. On the contrary claimed that roughening the resin surface with an acrylic bur weakened the bond.[25] Because of the stress concentration caused by discontinuities of the surface and entrapped air or gas at the interface, which could further weaken the bond by the created voids. On the other hand, if the surface roughening is done in a definite pattern, with high pressure during packing of silicone into the mold. This will provide proper flow of silicone elastomer into the grooves created on the acrylic substrate, without air or gas entrapment which will minimize the stress and weakening acrylic/silicone bonding. Additionally, the bonding strength of sandblasted and grooved acrylic/silicone was also improved. This results were in coincide with a study conducted by Bharti et al. (2021)[26] and Karla et al. (2015)[27] This could be due to fact that the retentive grooves acted as mechanical interlocking of peg like extension of silicone material into the grooves made on acrylic substrate, additionally, the grooves increased the surface area for the silicone elastomer to bond with acrylic resin thus, improving the bonding strength.

This study also evaluated the bonding strength between metal and silicone with different surface characteristics. And the results showed that when the surface of metal were sandblasted the bonding strength were improved noticeably. This results were similar to a study conducted by Latifi et al. (2014).[28] Additionally, Jaber et al. (2018)[29] also reported that the alumina air abrasion enhances the bond strength of the resin and the metal. Since, it increases the roughness depending on the particle size. This is due to fact that sandblasting systems removes loose contaminated layers and will increase surface roughness providing some degree of mechanical interlocking with silicone elastomer. Additionally, increased roughness will automatically increase the surface area for better bonding. Furthermore, similar bonding strength results were observed between grooved metal and silicone. Since, grooves will consequently increase the surface area. Thus more contact and bonding will occur between silicone and metaL. Likewise, a study by Shetty and Guttal (2012)[30] revealed that increasing surface area will increase bonding strength between silicone and substrate. However, in the present study, maximum bonding strength between metal/silicone were observed, when the surface of metal was sandblasted and grooved. This could be du to the fact that both techniques increased the surface area of the metal thus, providing better bonding strength.[15] In contrast a study by Unkovskiy (2021)[31] demonstrated that roughening of the metal surface did not improve the adhesion of silicone elastomers to metal and stated that the adhesion of silicone elastomers to metal and stated that the increase in contact area did not contribute to adhesion.

This result could be due to fact they used different chemical composition of the primer effecting the overall outcome of the study. However, Al-Mohammad (2020) stated that increase in surface roughness improves the bonding strength.
In the present study, the bonding strength between acrylic/silicone and metal/silicone where also compared and the results showed that metal/ silicone bonding strength is superior to bonding strength of acrylic/silicone for all surfaces characteristics. Nevertheless, a study by Haddad (2012) mentioned that bonding strength between acrylic/silicone is better than metal substrate. This may be due to that the metal in this study had rough surface compared to acrylic since it was not polished extensively. While, acrylic samples were polished and smoothed rigorously.

Conclusion

Within the limitations of the present study, it can be concluded that: There is no significant difference when acrylic surface was sandblasted. However, retentive holes improved the bonding strength between acrylic and silicone. While sandblast improved the bonding strength between metal and silicone elastomer. Lastly, metal bond better to silicone than acrylic resin for all tested groups.

Conflicts of interest

The authors report no conflicts of interest.

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