Evaluation of Effect of Laser Etching on Shear Bond Strength between Maxillofacial Silicone and Acrylic Resin Subjected to Accelerated Aging Process

Abstract

Objective: Maxillofacial prosthesis are supported by implants, require a retentive matrix to retain the suprastructure. The retentive matrix is made up of acrylic resin to which the silicone prostheses are anchored by micro-mechanical bond. The delamination of silicone away from the retentive matrix is a persisting problem in implant-supported maxillofacial prosthesis. Aim: This study aimed to evaluate the effect of laser etching on the shear bond strength (BS) between acrylic resin and maxillofacial silicone, after 24 h of fabrication and after 200 h of accelerated aging. Materials and Methods: The samples were prepared according to ISO/TR 11405:1994 in maxillofacial silicone and polymethyl methacrylate resin. The untreated samples were Group A (control), Group B (silicon carbide [SiC] paper abrasion 80 grit size), and Group C (erbium-doped yttrium aluminum garnet laser etching). Then, the samples were coated with primer and bonded to maxillofacial silicone. The samples were subjected to shear BS test in an universal testing machine after 24 h of fabrication and after 200 h of accelerated aging. Results: The results were statistically analyzed using one-way ANOVA and Tukey’s HSD post hoc test. The shear BS test after 24 h of fabrication showed better BS in SiC paper abrasion. The shear BS test after 200 h of accelerated aging showed better BS in laser etching compared to SiC abrasion. Conclusion: Laser etching produced better shear BS compared to conventional SiC paper abrasion after 200 h of accelerated aging process.

Keywords: Accelerated aging, laser, maxillofacial silicone, shear bond strength

Introduction

A maxillofacial prosthesis restores normal anatomy, protects the tissues on the defect area, and provides great psychological benefits to the patient. "Maxillofacial prosthetics is defined as the branch of prosthodontics concerned with restoration and replacement of both of stomatognathic and associated facial structures by artificial substitutes that may or may not be removed."[1]

Historically, auricular, nasal, and ocular prostheses were fabricated with various materials such as leather, cast metal, cloth, and vulcanite which had been found in Egyptian mummies. Since the 16th century, acquired surgical defects had been restored by prosthetic replacements using a variety of materials and techniques. Facial prostheses were first described by Ambrose Pare in 1575. Tissue undercuts were the primary mode of retention earlier. Until the late 1960s, medical grade skin adhesives were traditionally used in the rehabilitation of patients with extraoral defects. The skin adhesives are acrylic resin or silicone-based liquids that are applied to the margins of prosthesis before placement on face. Double-sided tapes were also used. The soft tissues in the irradiated site could become irritated by the prosthesis. To overcome these disadvantages, osseointegrated implants had been used to retain facial prostheses since 1979.[2] Thus, with the advancement of craniofacial implants, better esthetics, improved retention and stability of the prosthesis has become a reality.

The implant-retained extraoral prosthesis requires a retentive matrix to hold the retentive components such as bars, clips, and magnets. This retentive matrix is usually made of autopolymerizing resin, heat polymerizing, or visible light-cured acrylic denture resin. Thus, the acrylic retentive matrix acts as a substructure onto which the maxillofacial prosthesis is bonded.

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Maxillofacial silicones are polydimethyl siloxane polymers and have entirely different chemical structure from poly methyl methacrylate denture base resin. The bond of maxillofacial silicone to 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.\[3\]

The bond between silicone and acrylic resin can be improved by the application of primers which contain one or two types of silane coupling agents diluted in an organic solvent. It reacts with both resin matrix and maxillofacial silicone, by activating the surface through etching or promoting hydrogen and covalent bonds.\[3\] The bond could be further improved by the incorporation of surface treatments such as acid etching, silicon carbide (SiC) abrasion using various grit sizes, and sandblasting.

Laser has revolutionized the field of dental material science by altering the surface details of metal and acrylic resin. Erbium lasers are high-energy lasers compared to neodymium-doped yttrium aluminum garnet and potassium titanyl phosphate lasers which cause lots of small pits on the surface of denture base resin.\[4,5\] Hence, this study was done to evaluate the effect of laser etching and SiC abrasion on the shear bond strength (BS) between acrylic resin and maxillofacial silicone, after 24 h of fabrication and after 200 h of accelerated aging.

**Materials and Methods**

To evaluate the shear BS between maxillofacial silicone and acrylic resin, the samples were fabricated according to ISO/TR 11405:1994. Autopolymerizing acrylic resin (DPI Company, India) and room temperature vulcanizing silicone (MP SAI Enterprises, Pune, Maharashtra, India) were used to fabricate the acrylic resin and silicone samples.

A hollow brass cylinder was made as master die with an external diameter of 18 mm, internal diameter of 14.4 mm, and 25 mm height for the preparation of acrylic resin samples [Figure 1], and Teflon discs of 18 mm external diameter, 8 mm internal diameter, and 3 mm thickness were made for packing and curing of maxillofacial silicone materials [Figure 2].

The autopolymerizing acrylic resin was mixed in the ratio of 3:1 (polymer: monomer) and packed inside the hollow brass cylinder, and then allowed to polymerize at room temperature under pressure of 0.14 Mpa (20 psi) for 1 h. As per the manufacturer’s instructions, the maxillofacial silicone was mixed and cured in the Teflon disc at room temperature for 8 h. The acrylic resin samples without any surface treatment were considered control (Group A). The acrylic resin samples treated with SiC paper of 80 grit size (Carborundum universal) for 30 s under constant flow of water were considered Group B. The acrylic resin samples treated with laser (Fontonna, Fidelis Plus III MO21-3AF/4 serial no: 07000291) were considered Group C. Erbium lasers of wavelength 2.94 µm and energy level 3 W, 300 mJ, 10 Hz, 20 s long pulse duration were used for Group C [Figure 3]. The samples were washed in acetone water to remove the surface impurities and allowed to air dry at room temperature for 30 min. A total of 60 samples were prepared for this study. The surfaces of the samples were evaluated under the scanning electron microscope (Supra 55, Zeiss) [Figure 4].

According to the manufacturer’s instructions, the surface of the samples was coated with primer (Multisil, Bredent) using a brush and left for 30 min at 23°C ± 1°C and 50% ± 5% relative humidity. The maxillofacial silicone and acrylic resin samples were approximated at room temperature at 50% ± 5% relative humidity at a pressure of 0.09 Mpa. The samples were incubated at 37°C ± 1°C for 24 h and then shear BS test was performed after 24 h of fabrication.

The remaining samples were placed inside the Weather Ometer (Atlas Ci5000, Cipet) under filtered xenon light of 150 klx [Figure 5] for accelerated aging process. The weathering cycle prolonged for 120 min constituting of 18 min of wet weathering by controlled flow of distilled water (29°C ± 2°C), followed by 102 min of dry weathering (36°C ± 2°C). The relative humidity inside the aging chamber was approximately 70% and air pressure was 700–1060 hpa. The xenon light was applied for 200 h.

The shear BS between maxillofacial silicone and acrylic resin was evaluated using the universal testing machine (Instron 3382) at a crosshead speed of 5 mm/min [Figure 6]. The BS was calculated for each specimen using the following formula:

\[ BS = F/A \] (F - maximum force \( n \), A - cross-sectional area \( \text{[mm}^2] \)).

The results were statistically analyzed using one-way ANOVA, Tukey’s HSD post hoc test, and paired \( t \)-test. The significance value is <0.001 showed that the values were statistically significant.
Results

The mean shear BS value of the samples after SiC abrasion and laser etching was $13.37 \pm 2.256$ MPa and $8 \pm 1.701$ MPa after 24 h of fabrication and $10.05 \pm 2.009$ MPa and $11.32 \pm 3.727$ Mpa after weathering treatment [Table 1]. The mean shear BS values were statistically analyzed using one-way ANOVA. The mean significance value ($P < 0.001$) showed significant difference in shear BS among the groups in both methods [Table 2]. Multiple comparisons within the group were done using Tukey’s HSD post hoc test. The calculated $P$ value for the SiC-abraded group was 0.004 and the laser-etched group was <0.001 which showed significant difference between the groups in

samples fabricated after 24 h. The calculated $P$ value for SiC-abraded group was 0.729 and laser-etched group was 0.011, which showed significant difference between the group for samples subjected to accelerated aging process for 200 h [Table 3].

Graph 1 shows the mean shear BS between the control group, SiC-abraded group, and laser-etched group after 24 h of fabrication and after 200 h of accelerated aging. Group B showed higher mean shear BS after 24 h of fabrication and Group C showed higher mean shear BS after 200 h of accelerated aging compared to control.

Discussion

The implant-retained maxillofacial prostheses had failed because of delamination of maxillofacial silicone from the acrylic retentive matrix. The prostheses are subjected to

| Variable | Groups | $n$ | Mean±SD | Minimum | Maximum |
|----------|--------|----|---------|---------|---------|
| After 24 h | Control | 10 | 7.87±3.083 | 4.84 | 15.40 |
| | SiC abraded | 10 | 13.37±2.256 | 9.55 | 16.54 |
| | Laser etched | 10 | 8.00±1.701 | 5.80 | 10.97 |
| | Total | 30 | 10.15±3.483 | 4.84 | 16.54 |
| Weathered | Control | 10 | 6.86±1.358 | 5.17 | 8.92 |
| | SiC abraded | 10 | 10.45±2.009 | 6.79 | 13.34 |
| | Laser etched | 10 | 11.32±3.727 | 4.59 | 15.87 |
| | Total | 30 | 9.54±3.162 | 4.59 | 15.87 |

SiC=Silicon carbide, SD=Standard deviation

| Variable | Groups | Sum of squares | df | Mean square | $F$ | $P$ |
|----------|--------|----------------|----|-------------|-----|-----|
| After 24 h | Between groups | 197.220 | 2 | 82.390 | 16.917 | <0.001 |
| | Within groups | 157.122 | 27 | 5.829 | | |
| | Total | 354.342 | 29 | | | |
| Weathered | Between groups | 112.020 | 2 | 56.010 | 8.498 | 0.001 |
| | Within groups | 177.953 | 27 | 6.591 | | |
| | Total | 289.973 | 29 | | | |

Table 1: Mean standard deviation of shear bond strength values between silicone and acrylic resin after various surface treatments in 24 h of fabrication and weathering treatment

Table 2: One-way ANOVA for the mean values after 24 h of fabrication and weathering treatment
The bond of maxillofacial silicone 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.\[6,7\] The chemical structure of maxillofacial silicone (dimethyl siloxane polymers) and polymethyl methacrylate denture base resin is different and exhibits poor bonding characteristics. Hence, the primers are applied to increase the BS between silicone and acrylic resin, thereby preventing delamination of silicone and enhancing the longevity of the prosthesis. They increase the BS by activating the surfaces through etching or promoting hydrogen bonding and by covalent coupling, increasing the wettability of the substrate and by impregnating the surface layer with the polymeric ingredients.\[8\]

Prolonged exposure to daylight and to moisture greatly weakens the BS between maxillofacial silicone and acrylic substrate. Hence, accelerated artificial aging was used as a simulated condition, to evaluate the long-term strength of the bond between acrylic resin and maxillofacial silicone, after various surface treatments. In this study, 200 h was selected for aging because silicones further polymerize after aging, exhibiting higher BS than that of the unaged specimens. However, aging for longer periods had been reported to reduce silicones' elasticity and tear strength and also had degraded the BS.

Frangou showed that when the bonding surface of the acrylic resin samples was treated with 80 grit SiC paper under a constant flow of water, the BS increased.\[9\] Erbium lasers cause instant vaporization of water from the site and cause massive ablation of the surface, thereby increasing the surface area.\[10\] It was also proved that etching the surface of acrylic resin with erbium-doped yttrium aluminum garnet lasers at 300 mJ, 3 W, 10 Hz, long pulse duration had effectively increased the tensile BS between resin liner and denture base. Laser etching causes massive increase in surface area by creating numerous micro- and macro-porosities on the surface than SiC-abraded samples.\[11\]

The results of this study showed that the mean shear BS of SiC-abraded samples was more compared to the laser-etched
samples after 24 h of fabrication. The decreased BS in the laser-etched group was due to the initial stress accumulation at the silicone-acrylic interface. However, after 200 h of accelerated aging, laser-etched samples exhibited better BS which was due to the photo-polymerization induced by the artificial ultraviolet (UV) light. Patients, on an average, wear prosthesis for 8–12 h a day during which it may be subjected to UV radiation exposure. The exposure to UV radiation will induce further polymerization of the silicone prosthesis.

Statistical analysis showed that the exposure of silicone samples to artificial daylight after laser etching had increased the BS compared to the SiC abrasion. Since the silicone samples, when exposed to artificial daylight, get further photo-polymerized, i.e., the number of covalent bonds is increased between the polymer backbones, thereby increasing the cross-linking density. This increased cross-linking density is responsible for the higher BS in the aged laser-etched samples.

Thus, it was concluded that laser etching initially reduced the BS after 24 h of fabrication, but it increased the shear BS after exposure to artificial light of 200 h, than the SiC-abraded and control groups. Hence, in the long run, laser etching will definitely enhance the longevity of the prosthesis.

The limitations of this study were that the thickness of the primer applied on the sample surface could not be measured and its effect on the BS was unpredictable.

Clinical implication

Laser etching could be considered as a valuable surface treatment in improving the bond between maxillofacial silicone and acrylic resin compared to the conventional SiC abrasive surface treatment.

Conclusion

Within the limitations of the study, the following conclusions were drawn. The shear BS between maxillofacial silicone and acrylic resin surface treated with SiC abrasion using 80 grit size papers showed better BS after 24 h of fabrication compared to laser etching. The shear BS between maxillofacial silicone and acrylic resin surface treated with laser etching showed significant BS compared to SiC abrasion using 80 grit size after 200 h of accelerated aging.

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Conflicts of interest

There are no conflicts of interest.

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