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RESEARCH ARTICLE

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Evaluating The Effect of Humidity on Adhesion Strength of Skin Adhesive

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Background: Skin adhesive has been used for attaching certain medical application to the human skin for functional and/or esthetic purposes. Silicone adhesive is the most common type of skin adhesives that are recently used. This study aims to evaluate the possible effect of humidity on the performance of silicone skin adhesive.
Materials and Methods: Twenty-four silicone samples were divided into 2 main groups based on relative humidity (RH) exposure, namely 43% RH and 98% RH. Six samples from each group were tested for adhesion strength after 1 hour of adhesion, and the other 6 samples were tested after 2 hours of adhesion by conducting 180 degree peel test. The data were statistically analyzed for significant difference.
Results: The results showed that at 43% RH, the adhesion strength was higher than the 98% RH group. The results also showed that at both humidity settings the adhesion strength after the first hours of adhesion was lower than the adhesion strength after the second hour.
Conclusion: The silicone skin adhesive performance can be affected by the increase of relative humidity which needs more time of application to skin to reach the best adhesion function.

Keywords: *adhesions strength, humidity effect on adhesion, silicone adhesive, skin adhesives*

Introduction

Skin adhesives have been used for many years for retention of certain applications to skin. These applications vary in terms of functionality as some of them are therapeutic patches or devices, while other could be facial prostheses that restore esthetics and some functions.[1-3] Silicone polymeric gel by itself has been successfully used for wound healing and scar removal due to its surface properties that is compatible with the human skin.[4-6] In most cases, optimum adhesion to skin assures optimum functionality and esthetics.

Human skin is a complexly layered protective organ to the human body.[7,8] It has a surface area of about 2 square meters with surface properties that can be beneficial for certain medical applications.[9] Human skin consists of 3 basic layers which are epidermis, dermis, and the subcutaneous fat layer, while epidermis composed of four layers of distinct cells, the outermost cellular layer is keratin.[10]

Extra-oral or facial prostheses are retained in place by either skin adhesives or implant.[11-13] However, it is very common to use skin adhesives for facial prostheses retention to skin.[14] Although there were several attempts to physically

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modify skin adhesives for better adhesion performance[15,16], there are still several problems associated with skin adhesive such are related to adhesion longevity and adhesion strength. Focusing on the environmental factors, this study aims to evaluate the effect of relative humidity (RH) on the adhesion strength of silicone skin adhesive. The reason for selecting humidity to be studied is because of its possible impact on the adhesion performance of skin adhesives especially in certain areas where RH reaches high levels.

Materials and methods

Materials and Samples' Preparation

The materials used in this study were silicone elastomer (Factor II Inc., Lakeside, AZ, USA), woven nylon sheet as skin surrogate (Spenco, Durham, NC, USA), and skin adhesive (Hollister, Libertyville, IL, USA). A total of 24 silicone specimens were prepared (40 x 10 x 2 mm) and they were divided according to humidity grouping which were moderate (43% RH) and high (98% RH) with 12 specimens for each group. The specimens were also divided according to the time of application before the peel test which was the time from silicone sample adhesion to the artificial skin sample until it was being peeled off by the mechanical testing machine. Each group consisted of 12 specimens with application time of 1 hour and 2 hours which simulates the appropriate working time when wearing facial prosthesis.

Surrogate Skin Preparation

Artificial model for human skin was selected and modified to resemble human skin in terms of some mechanical properties related to adhesion and the test settings. The woven nylon surface of the surrogate was modified with a thin layer of olive oil and analyzed via Multiple Attenuated Internal Reflection Infrared (MAIR-IR) spectroscopy for chemistry similarities with biological skin. The surrogate skin samples were cut according to the dimensions of the silicone sample adhesion surface.

Peel Test

The adhesive application, which was liquid silicone as a main compound, was standardized by applying a load of 300 g over a roller to allow equal amount of force for adhesive distribution and surface wettability. The adhesive was applied to the silicone sample and left for 5 minutes before applying the sample to the artificial skin surface according to the adhesive manufacturer instruction this is to give enough time for the propellant to evaporate leaving behind the sticky adhesive. The standard mechanical technique peel test was according to American Society for Testing and Materials ASTM D3807–98 (2012) which is the test method for strength properties of adhesives peel by tension loading. The specimen and the surrogate skin were each clamped to the arms of the universal testing machine, and a 180-degree peel test was conducted by pulling the silicone sample off the surrogate skin at a speed of 2.22 mm/sec as shown in Figure 1.

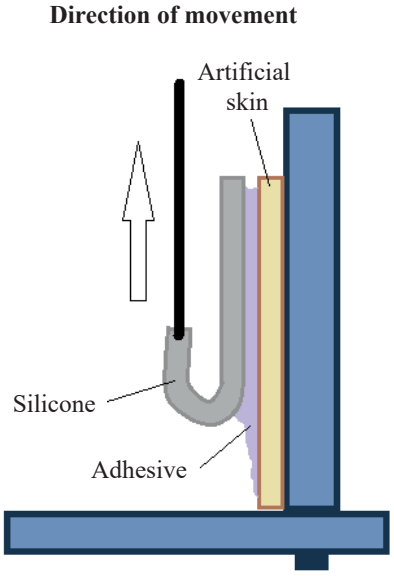

Figure 1. A 180-degree peel test.

Statistical Analysis

The statistical analysis conducted in this study was via IBM SPSS version 20 (IBM Corporation, New York, USA), Independent sample T test for significant difference of the adhesion strength between the silicone sample and the surrogate skin surface.

Results

After data collection from the adhesion test, the statistical analysis showed that there was a significant difference in the adhesion strength between the different humidity settings during the first hour of application ($p<0.05$) with higher adhesion strength in 43% humidity setting than in 98% RH. However, there was no statistically significant difference in the adhesion strength between the two settings after the second hour of adhesive application ($p>0.05$). The

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Table 1. Samples' adhesion strength at two different relative humidity settings and 1 hour application.

Groups Based on RH	n	Mean±SD	SE Mean	*p*-value
43% RH	6	183.00±6.93	4.00	0.001
98% RH	6	87.50±18.75	10.83	

RH: relative humidity; SD: standard deviation; SE: standard error. Units in gram.

Table 2. Samples' adhesion strength at two different relative humidity settings and 2 hours application.

Groups Based on RH	n	Mean±SD	SE Mean	*p*-value
43% RH	6	266.33±64.08	36.99	0.420
98% RH	6	215.50±74.27	42.88	

RH: relative humidity; SD: standard deviation; SE: standard error. Units in gram.

mean adhesion values were increased for both groups. This was associated with increased variances within each group after the second hour, as shown in Tables 1 and Table 2, and illustrated in Figure 2.

The statistical analysis also showed a significant difference in the adhesion strength between the different times of application ($p<0.05$). There was an increase in the adhesion strength after the second hour compared with the adhesion strength of the first hour of application in both humidity settings, as presented in Tables 3 and Table 4, and Figure 3.

Discussion

One of the most attractive and convenient methods of retention for maxillofacial prostheses is by using skin adhesives. Skin adhesives performance varies according to the type of the adhesive, the design of the restoration, and the skin properties in relation to the environmental factors. Titanium implant is another method for facial retention. However, it is considered to be expensive, requires surgical procedures, and not suitable for all cases because it requires a strong underlying bonny structure to be fixed in. Therefore, skin adhesives had become very popular not just for facial prosthesis, but also for many other skin-attached applications.

The main purpose of this experiment was to evaluate a common skin adhesive performance at two distinct humidity settings. Instead of using biological skin, a surrogate material was selected carefully after inspection and analysis. The silicone samples were applied to the surrogate skin substratum and kept in place

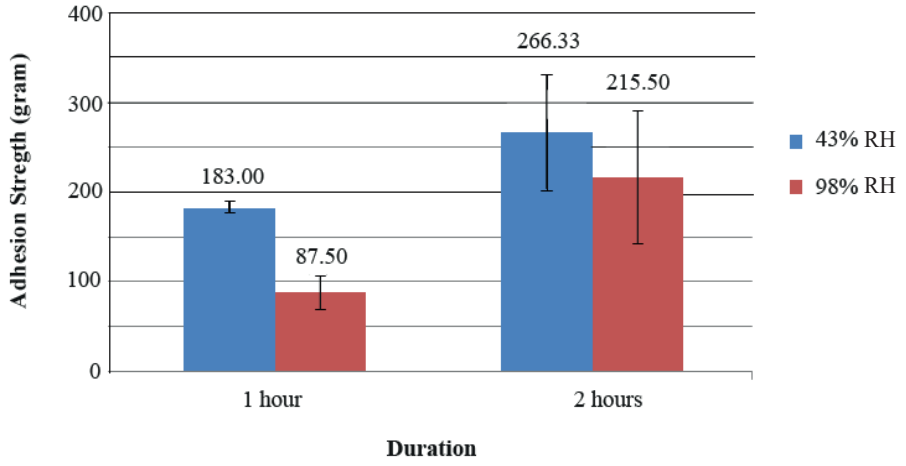

Figure 2. Adhesion strength at two different humidity settings and two periods of application time.

Table 3. Samples' adhesion strength between two different durations at relative humidity of 43%.

Groups Based on Duration	n	Mean±SD	SE Mean	*p*-value
1 hour	6	137.50±60.85	24.84	0.009
2 hours	6	281.19±90.90	37.11	

SD: standard deviation; SE: standard error. Units in gram.

Table 4. Samples' adhesion strength between two different durations at relative humidity of 98%.

Groups Based on Duration	n	Mean±SD	SE Mean	*p*-value
1 hour	6	187.33±15.11	6.17	0.015
2 hours	6	251.83±51.94	21.20	

SD: standard deviation; SE: standard error. Units in gram.

for two different periods of times before the adhesion strength test was conducted.

The study results showed that during the first hour of adhesion at moderate humidity, the adhesion strength in moderate humidity group was higher than the high humidity group ($p<0.05$). However, during the second hour of adhesion, both groups showed no significant difference in their adhesion strength. So, at higher humidity, the adhesion performance develops at a slower mode to reach its optimum strength. This could be attributed to the hydrophobic property of the silicone skin adhesive.

Since time is an important factor to consider while observing the adhesive performance[17], it was clearly observed that the adhesion strength of the skin adhesive in both humidity settings was significantly different during the first hour than the second hour of application. This means that skin adhesive does not reach its best and optimum performance during the first hour of application. However, it takes more time to perform better functionality. This could be due to the fact that propellants and other included chemicals evaporation rate from the liquid adhesive is slowed down because of the high RH which led to the weak cohesion strength of the silicone adhesive during the first hour test.

Because silicone is considered to be a hydrophobic polymer, the presence of moisture would significantly affect its performance, while hydrocolloid skin adhesive appeared to show stronger adhesion to skin in relatively

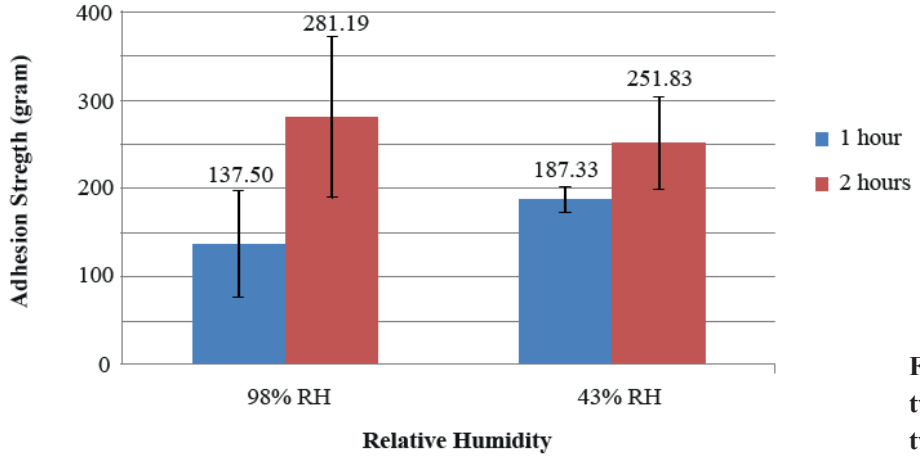

Figure 3. Adhesion strength for two different humidity settings at two period of application time.

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high humidity settings because it absorbs the surrounding moisture to develop stronger bond with the skin.[18] However, some studies suggested that silicone adhesive provides better management with skin bond in presence of moisture in terms of skin health, because, although hydrocolloid adhesive may show higher skin adhesion and moisture absorption, it would significantly affect skin health with time.[19]

It was reported in the literature that some mechanical properties of human skin change as the RH and temperature decrease or increase.[20] They showed that skin coefficient of friction increases with increased relative humidity as well as skin fluidity and ductility. Therefore, it is highly recommended to evaluate the effect of humidity on adhesion strength between skin adhesive and human skin surface. It is also recommended to evaluate other factors such as temperature (skin temperature and external temperature) with and without different humidity settings.

Conclusion

Within the limitations of this study, it was found that mechanical adhesion strength of the used silicone adhesive was significantly lowered by the increased humidity specifically during the first hour of adhesive performance. It was also found that regardless of humidity level, the silicone adhesion strength was increased during the second hour of performance. Further studies are required to include other factors that could possibly affect the silicone adhesion performance such as temperature it is also recommended to use biological skin for further experiments.

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