Research Article
Effects of Disinfection Methods on the Color Stability of Precolored and Hand-Colored Maxillofacial Silicone: An In Vitro Study

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Maxillofacial prostheses are used in rehabilitation of patients with facial defects. Typically, these prostheses are fabricated with medical grade silicone and are tinted corresponding to the patients’ natural skin color. However, exposure to environment and disinfectants can result in color changes. This study aimed to evaluate the effects of four different disinfection methods on the color stability of precolored and hand-colored maxillofacial silicones. Forty specimens each of precolored and hand-colored silicone were prepared. The specimens were randomly divided into eight groups (n = 10) and cleansed with four different disinfection methods. Disinfection was carried out six times/day for 60 days, simulating once-a-day disinfection for a year. Color evaluation was carried out at day 0 and day 60 using a UV-vis spectrophotometer. Color alterations were calculated by the CIE \( L^*a^*b^* \) system. Data were analyzed by two-way ANOVA with post hoc Tukey HSD and \( t \)-tests (\( \alpha = 0.05 \)). Disinfectants can affect the color stability of maxillofacial silicone. In our study, chlorhexidine solution and liquid soap resulted in the highest color change. Precolored silicone showed higher color stability than its hand-colored counterpart.

1. Introduction
Maxillofacial prostheses are extensively used in the aesthetic rehabilitation of patients with facial defects. Silicone elastomer is the most common material due to its physical properties, such as good strength, durability, flexibility, skin-like texture, and acceptable biocompatibility [1, 2]. Furthermore, it can also be colored intrinsically and extrinsically to confer to the patient’s skin color greatly improving aesthetics and acceptance by maxillofacial prosthodontists and patients alike [3]. Intrinsic coloring of silicone can be attained by the use of precolored silicone, which are available in different shades as made available by the manufacturer. It is also possible to manually incorporate different oil, powder, or silicone-based colors of various shades to a transparent silicone base, a procedure referred as hand-coloring. At times, both techniques can also be combined to attain the desired shade. Factors such as the production method of color, homogeneity of dispersion, and its ability to physically or chemically integrate with the silicone network can affect how the color pigments interact with the silicone network and its stability over time [3].

The discoloration of silicone is one of the primary disadvantages and can severely limit the shelf-life of the prosthesis. It occurs following exposure to external factors such as UV light, air pollution, cosmetics, temperature changes, humidity, and the use of various disinfection procedures due to the highly permeable nature of silicone [4–6]. Although many cleansing agents have been recommended, including water, neutral soap, and chlorhexidine [7], they should be used carefully as they can negatively affect the physical properties of the material [8]. Moreover, different methods of intrinsic coloring can also be one of the influencing factors for the color stability of silicone [9].
To the best of our knowledge, there had been no study on the effects of disinfectant on the color stability of precolored and hand-colored silicone. The objectives of this study were to evaluate the effects of intrinsic coloring techniques and disinfection methods on the color stability of maxillofacial silicone after a simulated 1-year period of cleansing, using the CIELAB color system. The understanding achieved from this research would support maxillofacial prosthetic education, research, and practice in the selection of appropriate disinfection agents or methods to minimize color alteration of maxillofacial silicone.

2. Materials and Methods

For the precolored and hand-colored groups, medical grade silicone (country shade, Multisil Epithetik; Bredent Inc, Germany) and colorless transparent silicone (Multisil Epithetik; Bredent Inc, Germany) were chosen, respectively. For each group, 40 specimens were prepared individually, and silicone base and catalyst were mixed in the ratio of 1:1 by weight as recommended by the manufacturer. A thixotropic agent (Thixo; Factor II Inc, USA) was also added to the silicone mixture (2 drops per 10 g of silicone) to aid in manipulation. Additionally, for the hand-colored group, 2% weight of intrinsic silicone coloration pigments (Santa Fe shade, FL-SK 11; Factor II Inc, USA) was added to the mixture (2 drops per 10 g of silicone) to aid in manipulation. For the precolored and hand-colored groups, medical grade silicone following disinfection by different solutions.

The statistical analysis was performed using IBM SPSS statistic with a significance level of $\alpha = 0.05$. The effect of silicone types and disinfection methods on color stability was analyzed by two-way analysis of variance (ANOVA). A post-hoc test (Tukey HSD) was used to analyze the color change on different disinfection methods regardless of the type of silicone. In addition, regardless of the disinfection methods, the effect of different types of silicones on color change was evaluated by the $t$-test.

3. Results

The present study rejected the null hypothesis that there would be no difference in the color stability outcomes of different types of intrinsically colored silicones following disinfection by different solutions.

The mean with standard error of color stability in each type of intrinsically colored silicone after 1-year of simulated disinfection is shown in Figure 1. The highest color change was observed in the MM-CHX group ($1.85 \pm 0.05$), with a statistically significant difference between the two combinations ($p < 0.001$). Two-way ANOVA showed that two main factors (types of silicone and disinfection methods), significantly affected color stability ($F = 2.47$, $p < 0.001$, and $F = 17.11$, $p < 0.001$, respectively). However, the interaction between the type of intrinsically colored silicone and disinfection method did not
significantly affect the color stability ($F = 1.11, p = 0.093$), as given in Table 1.

Regardless of the type of silicone, the highest color change was found following disinfection with 2% chlorhexidine solution ($1.77 \pm 0.13$), followed by chlorhexidine liquid soap ($1.27 \pm 0.11$), antibacterial soap ($0.83 \pm 0.09$), and the least with distilled water ($0.55 \pm 0.05$). A post-hoc test (Tukey HSD test) revealed that the color change of silicone after disinfectant with 2% chlorhexidine solution was significantly higher than distilled water ($p < 0.001$), antibacterial soap ($p < 0.001$), and chlorhexidine liquid soap ($p < 0.001$). However, the color stability following disinfection with antibacterial soap was not significantly different than distilled water ($p = 0.136$), as shown in Table 2.

Regardless of the disinfection methods, the $t$-test indicated that the hand-colored silicone group ($1.28 \pm 0.11$) had significantly higher color change than the precolored silicone group ($0.93 \pm 0.08$) ($p = 0.014$), as given in Table 3.

### 4. Discussion

Silicone prosthesis generally has a lifespan for 1.5–2 years [10]. One of the common problems following its use is the discoloration of silicone. Several environmental factors such as solar radiation, humidity, temperature, and airborne pollutants, as well as routine cleaning, can induce color alterations of maxillofacial silicone prostheses [11]. The primary mechanism has been attributed to chemical alteration within the material due to UV radiation in combination with air and moisture. This leads to bond breakage within the silicone polymeric network and color pigments, leading to their alteration or disintegration. Lightfastness values of colors can vary depending on their origin. Inorganic colors are ionic bond-based metal oxide and have greater color stability than organic ones that tend to replace their double or triple bonds [12].

In this study, the effects of the intrinsic coloring technique (precolored and hand-colored) and different disinfection methods on color stability were evaluated. The silicone (Multisil Epithetik) used in this study was based on a single manufacturer (Bredent Inc., GmbH and Co. KG, Germany). The precolored silicone in country shade was chosen as it had the most resemblance with the average Thai base skin tone. To minimize bias, the hand-colored specimens were tinted to produce a similar color such that the two groups were visually indistinguishable from one another. All specimens, whether precolored or hand-colored, showed different amounts of color alterations after disinfection and were in accordance with previous literature [5, 13–16]. Table 1 demonstrates that both factors, intrinsic coloring techniques and disinfection methods, significantly affected the color stability of silicone.

Precolored silicone showed significantly higher color stability over hand-colored silicone regardless of the disinfection method. Higher color stability could be assumed due to the stable binding of the colors with silicone polymeric network. Furthermore, regardless of the coloring technique, 2% chlorhexidine solution showed significantly higher color alteration than other disinfection methods. Conversely, past studies on color stability of silicone have shown varied results. Chamaria et al. found that antibacterial soap (Dettol) had higher color change compared to 2% chlorhexidine solution [13]; whereas, Goiato et al. found that 4% chlorhexidine solution showed the highest color alteration followed by neutral soap and Efferdent [14]. These inconsistencies in color change among the studies may have been due to differences in specimen preparation, methodology, condition for exposure, active ingredients present in the disinfectant, and study duration. In our observations, 2% chlorhexidine solution had significantly higher color alteration followed by chlorhexidine liquid soap, antibacterial liquid soap, and distilled water.
Aperceivablecolordifferencemayvaryfromoneobservertoanother;thus,inthisstudy,objectiveanalysisof
colordifferencewascarriedoutusingaspectrophotometer.

Color differences in the range of 0-1 represents color
identicaltothereferenceandisunperceivabletothenormal
humaneye,therangeof1-2canbeperceivedasacolor
differencemadebyexperiencedobservers,andvalues
>3canbeconsideredasclinicallyunacceptable[13],especiallyduring
maxillofacialrehabilitationwhenaestheticsisofaprimary
concern[17].Atsimulated360days,themeancolordif-
ferenceinallgroupswasslightlyraised.Althoughthecolor
changesassociatedwithdistilledwaterandantisepticsoap
remained below the perceivable value of <1 for both
precoloredandhand-coloredsilicone,themean
\( \Delta E \) of
MM-CHX,MM-CHXS,andP-CHXindicatedconsiderable
colorchangeswhichweresubstantialtobedetectablebyex-
periencedobservers.Visually,thespecimensappeared
darkerthantheothers.Thehighestmean \( \Delta E \) of 1.85
wasobservedinthehand-coloredgroupsdisinfectedwith2%
chlorhexidine gluconate. However, the value was still lower
thanthestudybyChamariaetal.wherepigmentedsilicone
showed \( \Delta E = 2.42 \) after exposure to 2% chlorhexidine and
\( \Delta E = 4.86 \) with antibacterial liquid soap (Dettol) [13].These
variationscouldhaveresultedduetothetypeofsilicone
[18]andintrinsiccolorsused[19],asChamariaetal.
utilized dry pigment, whereas this study utilized silicone
pigment, Factor 2, it is a blend of cosmetic pig-
mementscrushedintosiliconecross-linkingfluidand
designedtochemicallybindwiththesiliconepolymeric
network [21]. Even though the silicone pigments provided
better color stability compared to dry pigments, the values
were still lower than precolored silicone.

In our study, hand-colored silicone showed lesser
color stability; however, clinicians frequently use it
during prosthesis fabrication as the shade of precolored
silicone may not completely match the patient’s skin tone
in a clinical setting and additional coloring may be
needed. Furthermore, procedures such as hand rubbing
of the disinfectants could also cause frictional wear and
dislodgement of passively dispersed surface pigments,
thusestablishingtheneedforfrequentrestrainingofthe
prosthesis. In order to minimize color changes, it is
recommended to avoid strong disinfectants, such as
chlorhexidine and use precolored silicone when possible.
The addition of opacifiers or intrinsic UV light absorbers
mayalsominimizecolordegradation, buttheiraddition
shouldbe limited to reduce changes to the physical
properties of silicone [12].

One of the limitations of the research was that all
specimens could not be prepared simultaneously. This
could have led to some errors in obtaining a homogenous
dispersion of coloring pigments among the specimens,
especially with the hand-coloring technique. Uneven
distribution of color could inherently affect the color
values. However, our study considered mean \( \Delta E \) values
which could have minimized this error. In addition, due
to the product availability, our study investigated silicone
products from a single manufacturer, and therefore, the
results obtained may not be fully applicable for products
from other manufacturers. Further studies on the de-
velopment of agents or methods to minimize color al-
teration of maxillofacial silicone as well as on the
comparison of silicone products from different manu-
facturers should be required to enhance our under-
standing of the material.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean squares</th>
<th>F</th>
<th>P value</th>
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<td>5.70</td>
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<td>Type of silicons</td>
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<td>2.48</td>
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<td>Interaction (disinfection methods * type of silicons)</td>
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<td>0.37</td>
<td>2.22</td>
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<td>Error</td>
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<th>n</th>
<th>Post hoc test (Tukey HSD test)</th>
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<td>Distilled water (DW)</td>
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<td>0.05</td>
<td>20</td>
<td>DW/CHX &lt;0.001</td>
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<tr>
<td>2% chlorhexidine solution (CHX)</td>
<td>1.77</td>
<td>0.13</td>
<td>20</td>
<td>DW/CHXS &lt;0.001</td>
</tr>
<tr>
<td>Chlorhexidine liquid soap (CHXS)</td>
<td>1.27</td>
<td>0.11</td>
<td>20</td>
<td>DW/AS 0.136</td>
</tr>
<tr>
<td>Antibacterial liquid soap (AS)</td>
<td>0.83</td>
<td>0.09</td>
<td>20</td>
<td>CHX/CHXS &lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CHX/AS &lt;0.001</td>
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<td></td>
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<td>CHXS/AS 0.006</td>
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</table>

<table>
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<tr>
<td>Precolored</td>
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<td>40</td>
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<tr>
<td>Hand-colored</td>
<td>1.28</td>
<td>0.11</td>
<td>40</td>
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</table>

**Table 1: Two-way ANOVA results for color change (\( \Delta E \)) of silicone after stimulated 1-year disinfectant usage.**

**Table 2: Mean and standard error of color change (\( \Delta E \)) for four disinfection methods regardless of the type of intrinsically colored silicone.**
5. Conclusions

Chlorhexidine in both solution and liquid soap forms resulted in the highest color change in both types of intrinsically colored silicone compared to the other disinfectants. In addition, precooled silicone had greater color stability than hand-colored silicone. Further research on the development of agents or methods to minimize color alteration of maxillofacial silicone should be required to extend prosthesis life.

Data Availability

The data used to support this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References