Colour Difference Between Caucasian and Afro-Caribbean Skin Tone Silicone Elastomer Moulded in Type II and Type III Dental Stone

Keywords

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ABSTRACT

*Aim: The colour stability of the silicone is essential for the longevity of facial prostheses. This in vitro study investigates the colour degradation of two different skin shade silicones moulded in Type II and Type III dental stone. Methods & Materials: Two different types of dental stone were used to fabricate 168 silicone samples (n=42 for each group) using M511 maxillofacial silicone, which was coloured with Spectromatch Procolourants. The polymerisation was carried out at 85°C 1.5 hours. A spectrophotometer was used to record the colour differences (ΔE) of each group before and after polymerisation. The CIEL*a*b* formula was used to obtain the measurements and a one-way ANOVA was carried out for the statistical analysis of the data. Results: There is a statistically significant colour difference (ΔE) for all groups. For the Afro-Caribbean skin tone, Type III dental stone demonstrated the greatest colour change (ΔE = 4.36), whereas, for the Caucasian skin tone, it was the Type II dental stone (ΔE = 2.21). Conclusion: This study showed that regardless of the investing material, the colour of the silicone lightens after polymerisation. Both types of dental stone resulted in visible colour changes, with a ΔE ranging from 1.64 - 4.36.*

INTRODUCTION

The history of the facial prosthesis dates back to the Egyptians and the Chinese, who fabricated auricular, nasal, and ocular prostheses using various materials, such as wax, resins, and metal.[1,2] The purpose of maxillofacial prosthetics is to restore the form of missing or defective parts of the body, which could be a result of a disease, injury or congenital deformity. Restoration of these defects can be achieved by a surgical and/or a prosthetic approach, which aims to restore the patient's appearance, improve their self-esteem, and help them return to an active role in public life.[3-5]

The success of a restoration depends on the size and site of the defect, the skills of the prosthetist, and the properties of the material used for the restoration.[6,7] Polymeric materials, including acrylic, polyurethane and silicone elastomers, in particular, are some of the materials that have been used worldwide for this purpose over the years. Silicone elastomers were first used as maxillofacial material in 1960 by Barnhart,[8] and quickly took over the other materials. Although, this material exhibits some excellent properties, it also has some frustrating deficiencies, such as degradation of the properties over time, especially colour, which requires the renewal of the prosthesis after 9-12 months of service. This colour instability is related to factors such as ultraviolet radiation, humidity, air pollutants, patient's habits, used pigments, and the elastomer itself.[9-12] One of the greatest challenges a prosthetist faces is to reproduce the patient's exact skin colour, as the aesthetic outcome has a direct effect on the acceptance of the prosthesis and the psychology of the patient.[13,14] A successful prosthetic rehabilitation is not complete without considering the patient's psychosocial state and their quality of life. That is why the aesthetic outcome and the colour stability of the prosthesis are directly related to the success or failure of the treatment.[15-17] Studies have found that patient satisfaction declines over time, mostly due to the colour discolouration. Weathering (i.e. ultraviolet radiation, temperature, humidity), patient's habits and mishandling can cause unwanted discolouration in the prosthesis. Studies have reported that a colour change also occurs after the polymerisation of the silicone, which is believed to occur due to pigment loading, humidity, and temperature.[12,18-20] A lower polymerisation temperature (room temperature versus elevated temperature) results to a smaller degree of colour change after polymerisation. In regards to the investing material, colour changes may be due to colour leach from the stone to the silicone, which could be reduced, to some extent, by using a separating medium (i.e. Unifol).[21,22] This *in vitro* study aims to investigate this change of Caucasian and Afro-Caribbean skin shade silicones moulded in Type II and Type III dental stone. Our null hypothesis will be that there is no difference in the colour of the silicone when polymerised in Type II and Type III dental stone for Afro-Caribbean and Caucasian skin tone.

METHODS & MATERIALS

A pilot study, which determined the sample size was conducted, followed by the main study, which included four test groups. Each group had forty-two samples, including specimens of Caucasian and Afro-Caribbean skin tone moulded into Type II (Kaffir D) and Type III (Crystacal) dental stone. The skin tone mixtures were established by mixing individual Spectromatch Pro pigments.

The materials used for the fabrication of the samples included:

- Pink denture wax, which was used to prepare the wax samples.
- Spectromatch pre-pigmented M511 silicone, 10:1 ratio, which was used to prepare the silicone samples.

A two-piece aluminium mould containing an inner poly(tetrafluoroethylene) layer was used to prepare the rectangular wax samples, which were later moulded into the Type II and Type III stone moulds (*Figure 1*). The dimensions of the samples were decided as 40mm in length, 20mm in width, 8mm in thickness and 10g in weight. The base polymer and cross-linker of M511 maxillofacial silicone were mixed at a 10:1 ratio, to fabricate the silicone samples. Two anonymised colour recipes (one Afro-Caribbean and one Caucasian skin tone) (*Table 1*) were obtained from the patients' database of King's College London Dental Institute Department of Spectromatch colour formulation software. This software works in combination with a spectrophotometer, which after recording the skin shade of the individual generates a recipe of specific pigments loading and silicone required for the reproduction of the skin shade.

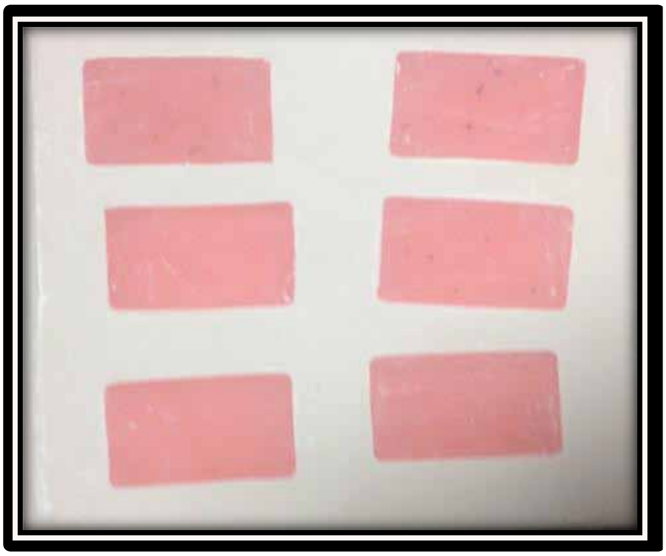

Figure 1: The rectangular wax samples moulded in Type II stone mould

Table 1. Mass (g) of pre-pigmented silicone used to produce each sample with a total mass of 10g.

Caucasian skin tone	Afro-Caribbean skin tone
Light Grey (2.10g)	Deep Grey (0.54g)
Cream (2.16g)	Cream (2.70g)
Pink (2.28g)	Red (0.79g)
White (3.46g)	Umber (5.97g)

The pre-pigmented silicone used for the silicone samples was weighed with high-precision scale and centrifugally mixed twice for 30 seconds at 1800 rpm in a Speed Mixer. This was to produce a more homogeneous and dense mixture and reduce the formation of air bubbles, which could compromise the elasticity, elongation, tear resistance, and aesthetics of the material. Once the mixture was ready, it was placed into the moulds ensuring no air was entrapped.

While the silicone was still un-polymerised, a clear thermoplastic sheet (0.8mm thick) was placed on the top of the silicone on the mould. This was done to be able to record the colour of the silicone before polymerisation. Without the thermoplastic sheet it would have been impossible to make the measurements. To limit the interference of the sheet on

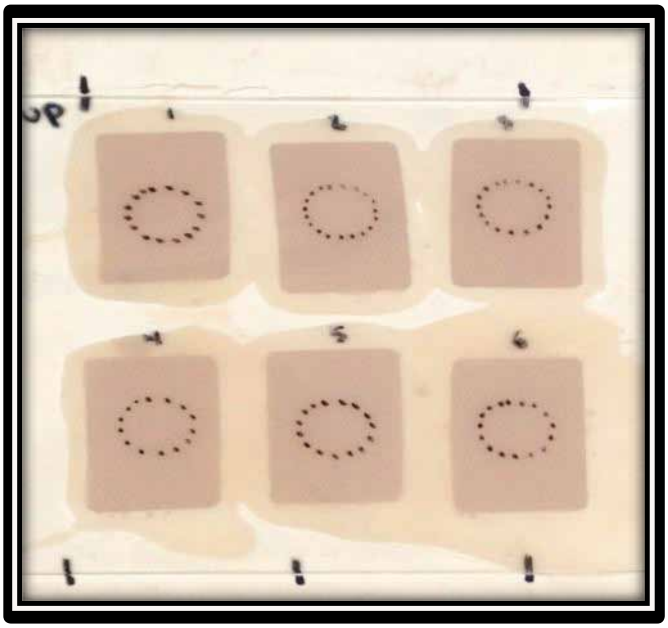

Figure 2: A circle was marked on the thermoplastic sheet on the centre of the sample to ensure that the sample is measured at the exact same place each time

the colour measurement, the thickness of the sheet was kept as low as possible. In addition, a circle was marked on the thermoplastic sheet in the centre of each sample *(Figure 2)* to ensure that the sample was measured at the exact same place each time. Twenty-eight stone moulds were prepared to accommodate a total of 168 samples (n=6 for each stone mould). All moulds and the thermoplastic sheets were used only for one set of samples (six samples in each mould, before and after polymerisation). Twenty-eight stone moulds (two Type II and two Type III stone moulds) were used to produce 168 silicone samples in four groups (14 x 6 Afro-Caribbean skin shade samples and 14 x 6 Caucasian skin shade samples).

The wax samples were moulded into the Type II and Type III stone moulds to create the voids for the silicone samples. To ensure a consistency, all stone moulds were prepared at the same time, and under the same weathering conditions. The wax was boiled out, and the moulds were allowed to dry for 24 hours before packing the silicone.

A separating medium (Unifol) was applied on all stone moulds and allowed to dry. The silicone was placed into the moulds and a thermoplastic sheet was placed on the top of it, making sure the circle on the sheet is in the center of the silicone sample. Lines were marked on the thermoplastic sheet and the stone to ensure correct alignment of the sheet after polymerisation. The colour measurements were recorded using a spectrophotometer. The thermoplastic sheet was removed; the mould was closed down gently and placed under a hydraulic press (1.2 Kg/N) for 20 minutes. Finally, the mould was placed into a pre-heated oven and left to polymerise at 85^{o}C for 1:5 hour *(Figures 3 & 4)*.

The colour of the samples was assessed at baseline (before polymerisation) and immediately after polymerization using the spectrophotometer. The samples were cleaned with water and wiped dry to remove any artifacts and stone impurities from the surface of the silicone sample, which could affect the readings. As incorrect values of colour may result due to light edge loss of the spectrophotometer beam outside the aperture area, two individual colour measurements were taken for each specimen. For the assessment of the colour, the same thermoplastic sheet was used pre & post polymerisation to ensure the validity of the readings and minimise bias. After polymerisation, the marked lines of the thermoplastic sheet were aligned with the marked lines on the stone, to ensure the marked circle is in the center of the sample and the colour is measured at the exact same place

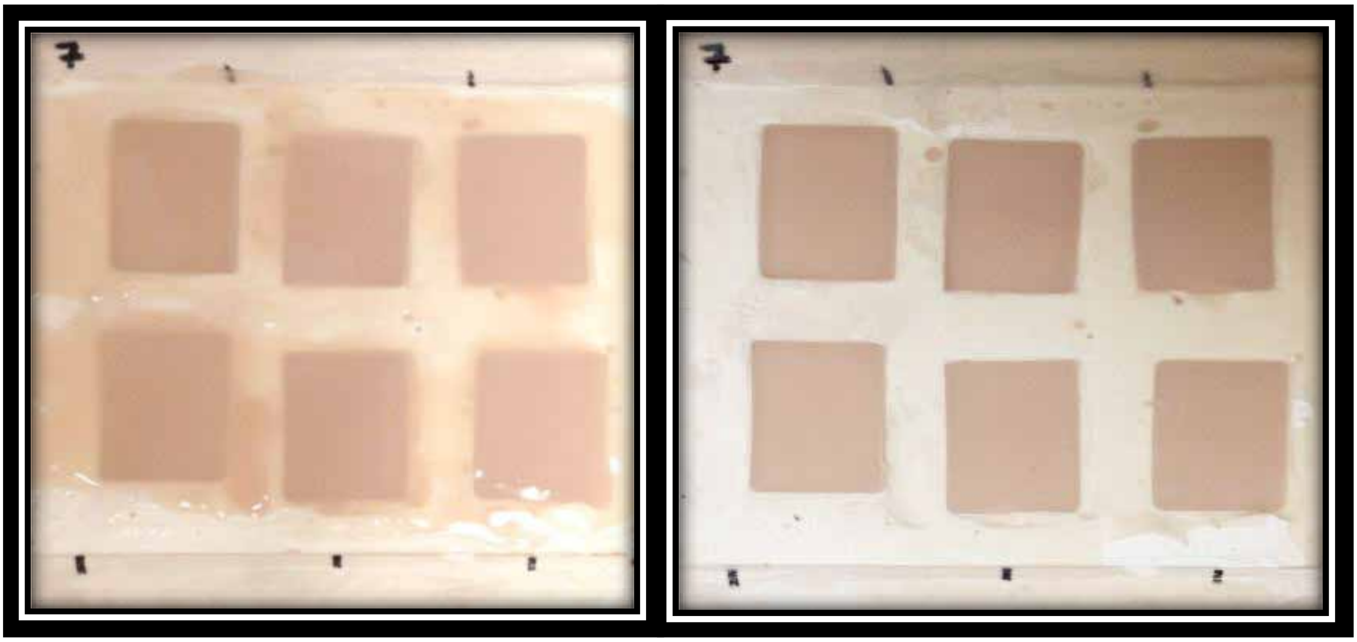

Figure 3 (R) and 4 (L): Caucasian skin shade silicone moulded into the Type III dental stone before(R) and after(L) polymerisation

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on the sample. In addition, a second set of measurements was recorded without the clear thermoplastic sheet, to record the exact colour of the silicone samples. The second set of measurements was compared to the primary set to determine the interference of the thermoplastic sheet on the colour of the samples, which was found to be non statistically significant.

The above skin tones were selected, as they are the most commonly used in studies when comparing fair and dark skin shaded silicone. This also happens because they contain the greatest amount of red and yellow pigments, which are the less stable among the used pigments. In addition, Caucasian and Afro-Caribbean skin shade are the most commonly seen among the patients in the UK, while the Type II and Type III dental stones are currently the most readily available investing materials for maxillofacial prosthesis in the market.

Two colour measurements were recorded for each sample (pre & post polymerisation), with the mean value representing the L*a*b* coordinate. The data was entered onto a spreadsheet and the colour difference (ΔE) was calculated using the CIEL*a*b* 1978 system. The mean and standard deviation (SD) of each group were calculated. Because these samples served also as a control group (samples were measured before and after polymerisation), ΔE was calculated from the mean L*, a* and b* values.

A statistical software was used for the statistical analysis of the obtained raw data. The statistical significance was set at $p < 0.05$. The sample mean of each group was reported as the mean ± SD. The skin shade and the type of the dental stone were considered categorical variables, whereas time (pre & post polymerisation) was considered a continuous variable.

RESULTS

The data was subjected to a one-way analysis of variance (ANOVA) to evaluate the difference between the two types of stone on the colour of the pigmented silicone elastomer. All data were subjected to Levene's test of homogeneity of variance ($\alpha = 0.05$). In addition, a t-test for independent data was performed for each group to investigate the effect of each type of stone on the colour change of the silicone ($p < 0.05$), while the pre & post polymerisation date were submitted to an unpaired t-test. A higher ΔE represented a greater colour difference (i.e. ΔE = 4.36 for Afro-Caribbean skin shade silicone moulded into Type III stone), while a lower ΔE represented a less significant colour difference (i.e. ΔE = 1.64 for Caucasian skin shade silicone moulded into Type III stone). The four groups were organised as below:

- Group 1 -› Afro-Caribbean skin shade silicone moulded in Type II (Kaffir D) stone
- Group 2 -› Afro-Caribbean skin shade silicone moulded in Type III (Crystacal) stone
- Group 3 -› Caucasian skin shade silicone moulded in Type II (Kaffir D) stone
- Group 4 -› Caucasian skin shade silicone moulded in Type III (Crystacal) stone

A data summary of ΔE before and after polymerisation for all groups is presented in Table 3. The lowest colour change was observed in Group 4 (ΔE = 1.64), while the greatest was observed in Group 2 (ΔE = 4.36). The rest ΔE values varied between the above figures. The samples for the Afro-Caribbean skin shade demonstrated the highest colour changes for both types of stone (ΔE = 3.92 for Group 1 and ΔE = 4.36 for Group 2). The samples for the Caucasian skin shade demonstrated the lowest colour changes, with Type III stone having an acceptable effect on the colour of the silicone (ΔE = 1.64). Based on the above, a statistically significant difference was found for all four groups ($P < 0.0005$).

The mean ΔE values for all groups at power level 0.8 (80%) are illustrated in Table 2, which shows the Bonferroni test on multiple comparisons of dependent variable (ΔE) based on the observed means. Significant difference ($P < 0.0005$) was found when comparing the groups with each other. The bold characters represent the significant difference for each comparison.

Table 2. Bonferroni test on multiple comparisons of dependent variable (ΔE) at significant level α = 0.05. The bold characters indicate the significant difference between the groups.

Groups (a)	Groups (b)	Mean difference (a - b)	Standard Error	Significance
	2	-0.4378	0.15752	0.037
1	3	1.7068	0.15752	0.000
	4	2.2788	0.15752	0.000
	1	0.4378	0.15752	0.037
2	3	2.1446	0.15752	0.000
	4	2.7166	0.15752	0.000
	1	-1.7068	0.15752	0.000
3	2	-2.1446	0.15752	0.000
	4	0.5721	0.15752	0.002
	1	-2.2788	0.15752	0.000
4	2	-2.7166	0.15752	0.000
	3	-0.5721	0.15752	0.002

level α = 0.05. The bold characters indicate the significant difference between the groups.

An increase in ΔL* values after the polymerisation of the silicone was observed for all samples, indicating a lightening of the samples after polymerisation. One would argue that ΔL* values cannot stand on their own and that they make sense only as a part of the ΔE equation. The reason the author uses this value on its own is to show that the colour of the silicone after polymerisation tends to lighten rather than darken.

Irrespective of the type of the stone and the skin shade, all samples underwent some chromatic alteration (ΔE > 0). Figures 5, 6, 7 and 8 present the L* value readings for all four groups before and after polymerisation. Colour measurements were recorded at baseline (before polymerisation) for each of the four groups using a clear thermoplastic sheet. A total of four measurements were recorded for each sample, two before and two after polymerisation. The colour difference (ΔE) was calculated using the CIEL*a*b* 1978 colour difference formula and the obtained data was analysed for all four groups.

The ΔE in all groups ranged from 0.73 – 6.06, with most of the values being above the visual level of perceptibility (ΔE = 0.9 for fair skin tone and ΔE = 1.3 for dark skin tone) *(Figures 9 & 10)*. The lower ΔE was recorded for Group 4 and the highest for Group 2. The analysis of the ANOVA revealed that there was a statistically significant difference ($p < 0.0005$) when comparing the tested groups with each other.

Figure 11 presents the difference in the mean ΔE values for all four groups. Group 1 had a mean ΔE of 3.92 with a SD of 0.77, Group 2 had a mean ΔE of 4.36 with a SD of 0.92, Group 3 had a mean ΔE of 2.21 with a SD of 0.59, and finally Group 4 had a mean ΔE of 1.64 with a SD of 0.50. As it is evident from the graph, when comparing the mean ΔE values, there is a statistically significant difference when comparing Group 1 and 2, and Group 3 and 4.

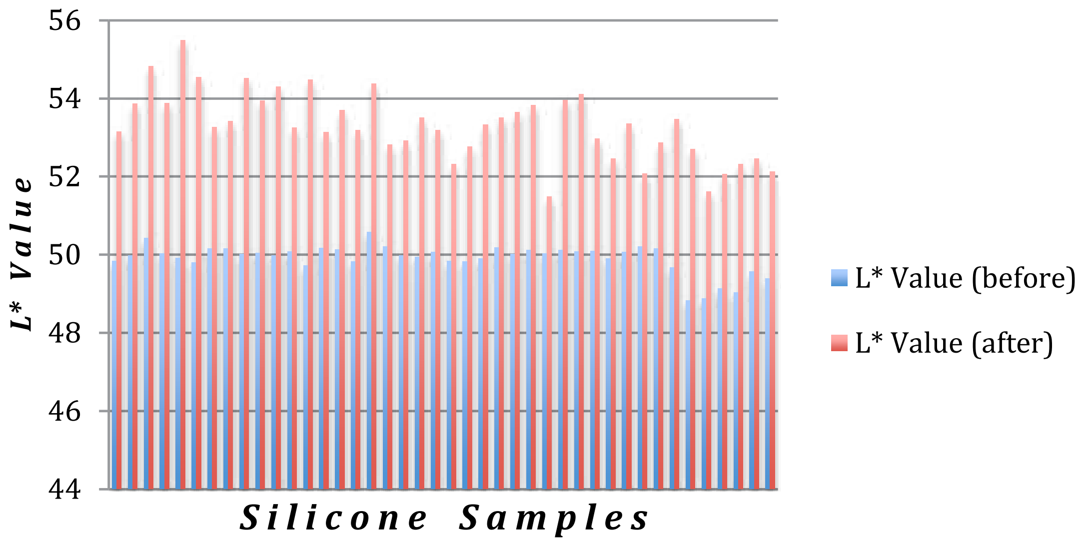

Figure 5: L* values before and after polymerisation for Group 1

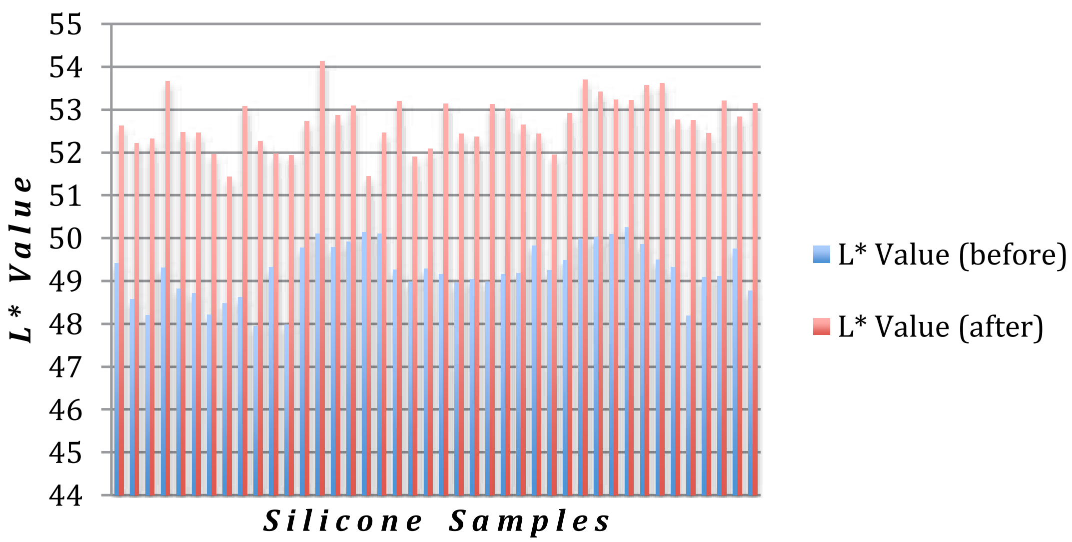

Figure 6: L* values before and after polymerisation for Group 2

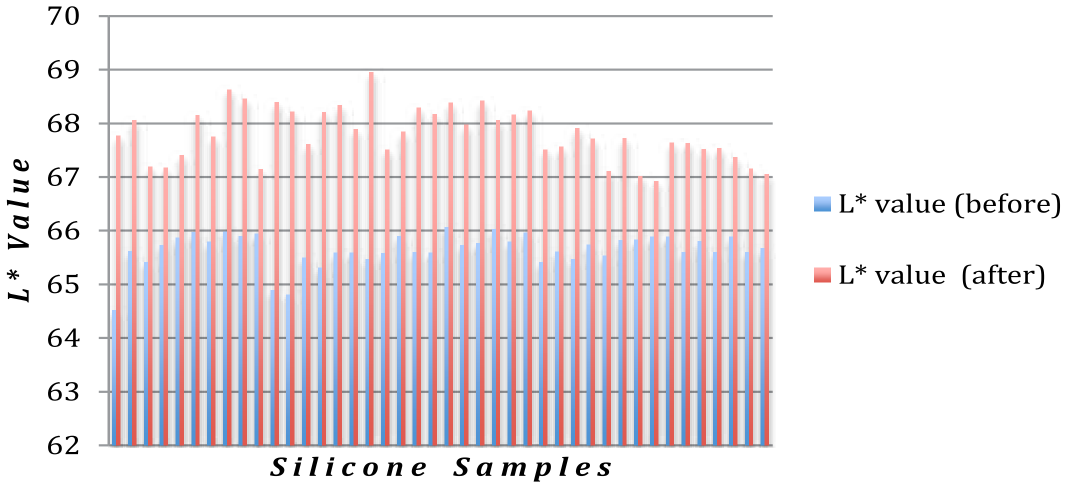

Figure 7: L* values before and after polymerisation for Group 3

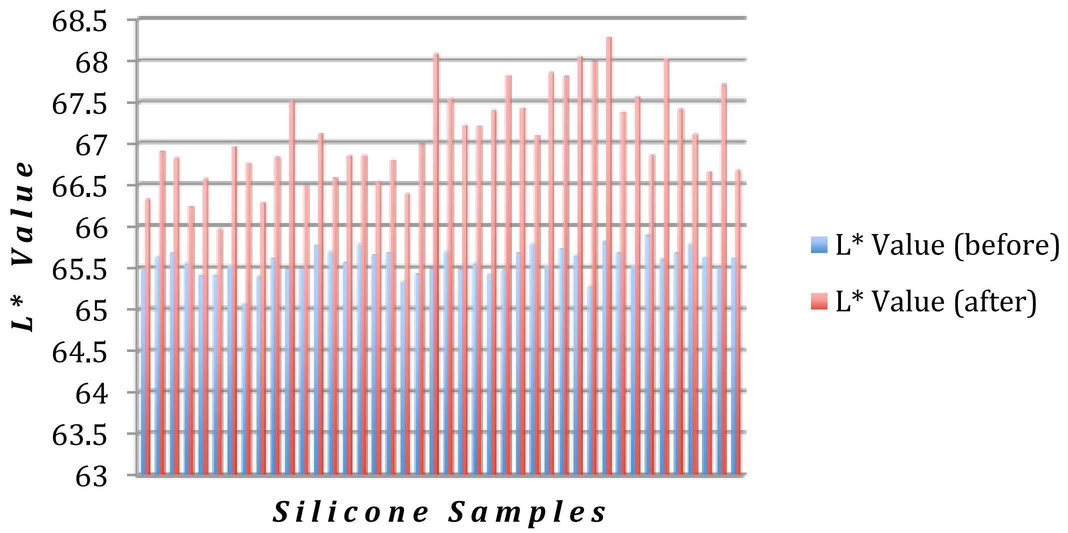

Figure 8: L* values before and after polymerisation for Group 4

Figure 12 presents the difference in the mean L* values for all four groups. Group 1 had a mean L* of 3.40 with a SD of 0.77, Group 2 had a mean L* of 3.48 with a SD of 0.65, Group 3 had a mean L* of 2.15 with a SD of 0.61, and finally Group 4 had a mean L* of 1.54 with a SD of 0.54. As it is evident from the graph, when comparing the mean L* values, there is not a statistically significant difference between Group 1 and 2, while when comparing Group 3 and 4, a statistically significant difference on the mean L* values is notices.

DISCUSSION

A correct colour match of the patient's skin shade plays a critical role in the success of the prosthetic rehabilitation. Matching of the skin colour is a challenging procedure for the prosthetist. Spectrophotometry and colorimetry are widely used to evaluate colour, while ΔE values are used to describe whether a colour difference is perceptible to the human eye.[28-30] Other authors[31-33] have reported perceptibility and acceptability thresholds ranging between 0.8 – 1.1 and 1.8 - 3.0 units, respectively. However, as the above studies report a broad range of values probably due to different methodology and materials used to conduct them, further investigation

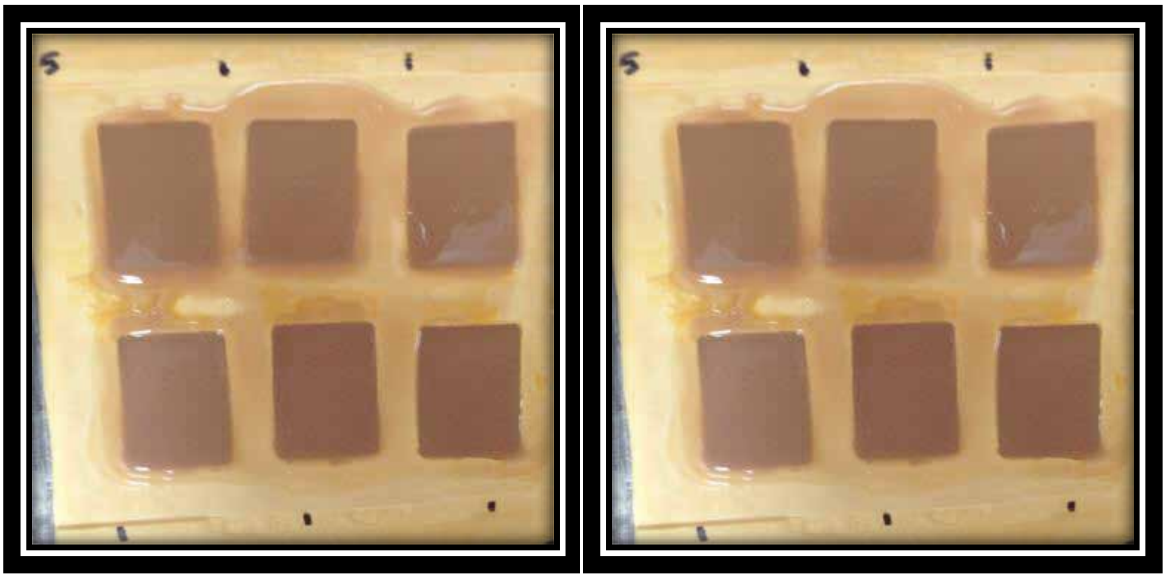

Figure 9 (R) and 10 (L): Afro-Caribbean skin shade silicone before(R) and after(L) polymerisation moulded in Type II stone. For this group, the ΔE ranged between 2.20 – 5.49.

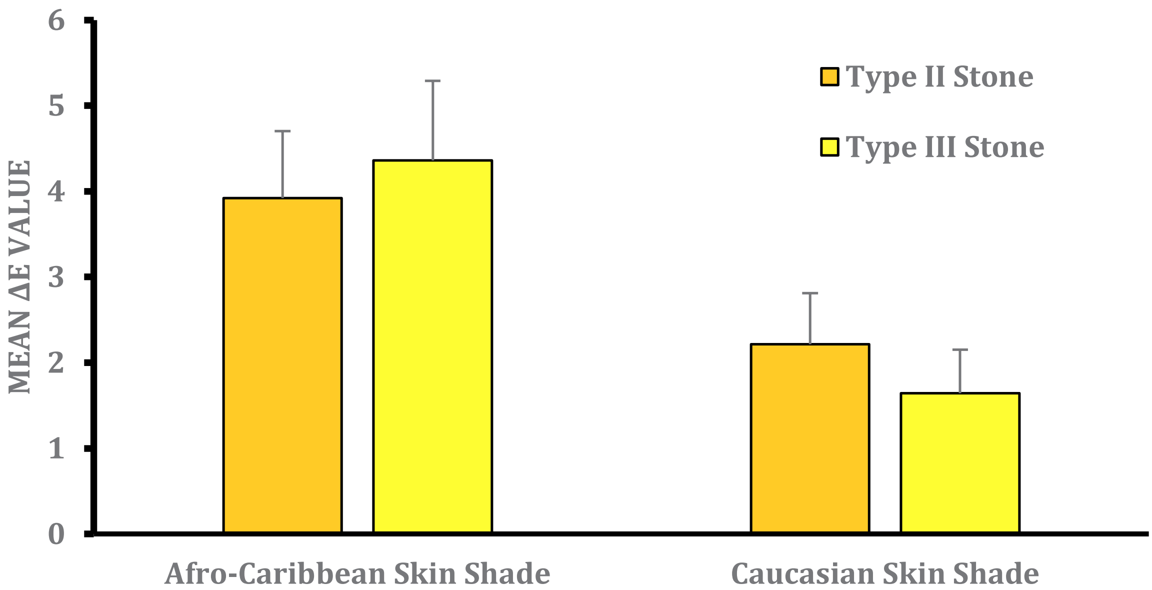

Figure 11: The mean ΔE for all four groups

about the perceptibility and acceptability thresholds should be conducted to narrow down the range in these values and be used as a referral point to all studies to make possible direct comparison.

The trained human eye (i.e. prosthetist) can detect ΔE > 1,[34,35] while an untrained eye usually cannot distinguish ΔE < 2. Although a ΔE between 1 - 2 units have been reported to be visually perceptible,[13,36] it can still be clinically acceptable and be regarded as satisfactory by the patient, provided the difference is within their "acceptable" threshold. Williams and Warwick[37] studied the colour stability of soft silicone materials, and reported a 50-50% acceptability threshold of ΔE = 1.8 for the fair skin shade and ΔE = 2.6 for the dark skin shade. In addition, darker surfaces have been found to reflect less light than lighter surfaces, which makes them appear darker.[38,39]

It is evident from the literature that research is limited in the effect of the type of the stone on different ethnic shades silicone. Only two studies[21,22] have measured the colour stability of the silicone when moulded in different types of stone. Those studies evaluated the effect of different types of stones, the separating mediums and the temperature of polymerisation on Asian and Turkish skin tone silicone, respectively. There is no record in the literature evaluating other ethnic skin tones; therefore, the results of this study may prove to be useful. While Sethi *et al.*[22] used wax rectangular samples to create the voids on the stone

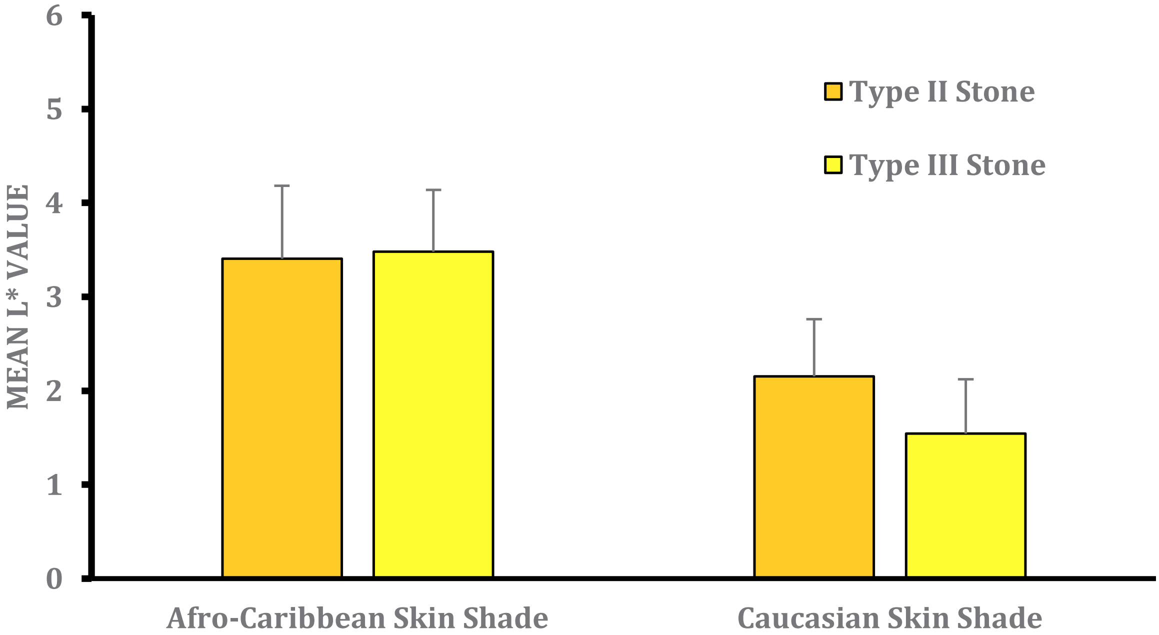

Figure 12: The mean L* values and the SD for each groups

moulds, Cifter *et al.*[21] used erasers samples. In addition, they did not use any separating medium on the voids of the mould to be able to evaluate the direct effects of the stone onto the silicone. It is believed that this might have affected their final results, as the separating medium offers a barrier between the investing material and the silicone, limiting the transfer of any impurities from the stone to the elastomer, which could add to the colour difference.

Studies have reported that colour of polymerised silicone is different from the colour matched in the presence of the patient, especially when die stone is used to mould the silicone. Although the separating agents seem to work as a barrier between the silicone and the stone, leaching of the stone into the silicone can still happen. All the values obtained in this study were higher than the threshold value that the human eye can perceive (ΔE = 1), which agrees with previous studies.[21,22] This indicates a significant colour change is occurring during polymerisation of the silicone regardless the type of the stone used.

Silicone discolouration has been shown to be mainly due to the loss of red pigment, and less by to yellow and burnt sienna pigments, which are reported to be more colour stable. In addition, factors such as the type of silicone elastomer, weathering and ageing are related to silicone degradation. Several studies[5,40,41] have reported that colour alteration afterthe fabrication of the prosthesis might result from chemical changes on the polymeric chain, loss of pigments, release of sub-products during the continuous polymerisation, and the fact that the colour of the investing material might penetrate the surface of the silicone and affect the colour of the sample.

In this study, the analysis of the ΔE showed that for Afro-Caribbean skin tone silicone Type II stone result in lower colour alterations than the Type III stone. On the other hand, the Type III stone is more suitable for Caucasian skin tone silicone, resulting in lower colour alteration when compared to Type II stone for the same skin shade. The majority of the colour changes (ΔE) were above 1 unit and, therefore, above the visual level of perceptibility. This agrees with previous studies, which have reported that the investing material and the polymerisation temperature influence the colour stability of the silicone elastomer during polymerisation.

All specimens moulded in Type II stone showed a statistically significant difference compared to the specimens moulded in Type III stone. According to Lynch and Livingston,[42] wet surfaces (unpolymerised silicone) appear darker than dry surfaces, making the colour difference after polymerisation more noticeable, which agree with Cifter *et al.*,[21] who suggested that HTV silicone should not be polymerised in white, yellow or brown stone moulds, as it makes the elastomer appear more yellow, while moulding RTV silicone in white, blue, yellow or green stones, makes the silicone appears greener. This seems to disagree to an extend with the present study, as Type III stone (white colour stone) although it showed a poor colour stability for Group 2 (ΔE = 4.36), gave the best results for Group 4 where the colour difference was below the acceptability thresholds (ΔE = 1.64). The analysis of the data from this study showed that Afro-Caribbean skin shade silicone result in less discolouration when moulded into Type II stone (yellow colour stone) (ΔE = 3.92) instead of Type III stone (ΔE = 4.36), whereas Type III stone (white colour stone) results in less discolouration for Caucasian skin shades (ΔE = 1.64) instead of Type II stone (ΔE = 2.21).

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The slight differences in the finding between the studies is believed to have happened because different materials and research methodologies are used in each study, making a direct comparison impossible. Both previous studies[21,22] suggest that investigation on different skin shades (dark and fair skin colour) should be carried out, which makes the results of this study beneficial. In addition to that, the author believes a study with a larger number of samples and more variable (including more skin tones and more investing materials) would be beneficial in determining the best investing material for each skin shade.

A comparison between pigmented and non-pigmented silicone has been studied over the years, to evaluate colour stability of the pigmented silicone. The authors agree that the colour stability depends on the type of the pigments (organic versus inorganic) and the silicone (HTV versus RTV) used. Several authors[4,39,43] have shown that samples with red pigments discolour at a higher rate than the ones with yellow pigments.

CONCLUSION

Within the limitations of this *in vitro* study, the following conclusions were drawn:

1. Regardless of the type of the investing material used for moulding the silicone samples, colour changes were observed for all pigmented samples.
2. Type II stone is recommended for moulding Afro-Caribbean skin shade silicone as it results in less colour discolouration after polymerisation.
3. Type III stone is recommended for moulding Caucasian skin shade silicone as it results in less colour discolouration after polymerisation.
4. No statistically significant difference were observed in the L* values of Group 1 and 2, which indicates that Afro-Caribbean skin shade silicone is subject to colour lightening after polymerisation regardless of the type of the stone used.
5. Type II stone produces a greater colour difference on Caucasian skin shade silicone after polymerisation when compared to Type III stone, resulting in a lighter colour.

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