Review Article

A tele dentistry-based technique to remotely analyze maxillofacial prostheses colors using virtual color calibration

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ABSTRACT

The presented technique highlights the remote color evaluation of skin and an auricular maxillofacial prosthesis using color-corrected images facilitated by a custom 18% middle-grey virtual background in a teleconferencing software application. The International Commission on Illumination (CIE) introduced L, a* and b* color values were extracted from images using a photo editing software and plotted within an equation to evaluate the Euclidean color differences (ΔE) at different times of the day where the L, a* and b* values from the healthy ear images were considered as standard. Consistent ΔE color differences were produced and there were no significant differences in L, a* and b* color coordinates when compared statistically to professional color calibration tools. The presented technique is a viable, cost-effective alternative for evaluating color changes of auricular prostheses that can be used to guide the need for replacement utilizing a teledentistry platform.

Keywords

Tele dentistry; color; Maxillofacial Prosthesis.

INTRODUCTION

Prosthodontic treatment planning in the age of digital dentistry makes use of remote working while maintaining the quality of care given to patients. This approach enables the operator to swiftly carry out the procedure and move forward with the planned treatment program. However, outside large cities, strategic locations, or big centers, there is a severe lack of qualified

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Bangladesh Journal of Medical Science Vol. 24 No. 02 April'25

DOI: https://doi.org/10.3329/bjms.v24i2.81551

maxillofacial prosthetists or anaplastologists capable of performing manual fabrication of extraoral prostheses. As a result, cases of facial defects are consequently sent from one location to another and leading to prolonged waiting times for rehabilitation with an additional oral prosthesis.

Teledentistry, an information-based communication system, offers an alternative solution to mitigate the issue remotely.[1] Furthermore, prosthetic silicone elastomers have inferior color fastness, indicating less resistance to color fading. This has led to reports that 29% of patients who were provided with maxillofacial prostheses had their prostheses remade within a year. Although several studies have reported enhancing the color stability of the silicone extraoral prosthesis, over time, these protheses still lose their natural attractiveness and become noticeable in public, ultimately failing the prosthetic therapy. [2–4]

The color evaluation of a prosthesis can be performed either visually against shade guides or by using professional instruments such as a spectrophotometer or colorimeter.[5] However, both techniques require extensive training, are technique sensitive, require face-to-face communication, and are subjected to inter-device and observer dependent variabilities.[6] In contrast, the use of professional digital cameras and smartphones is advocated due to the ease of data capture, manipulation and color analysis; streamlined communication to dental technicians; and immediate visual feedback and education for the patient.[7] Considering the steep financial investments required for a professional clinic studio, the use of built-in cameras on personal devices (smartphones, tablets, and computer webcams) have become a more feasible option that incorporates an efficient workflow involving limited patient contact.

The presented technique describes the analysis of auricular prosthesis colors from webcam and smartphone camera photographs using teleconferencing software and a custom virtual color calibration tool. The technique facilitates analysis of color changes in any extraoral silicone prosthesis for the person performing the video conferencing.

Technique

Steps of preparation before technique implementation

1. Fabricate an extra-oral silicone prosthesis. The current report follows the evaluation of an implant-supported silicone ear prosthesis. Capture images of the prosthesis and the patient's healthy ear (opposite) against a solid matte colored background by asking the patient to hold a multi-color calibration card (Spyderchekr 24; Datacolor, Trenton, NJ, USA) at 50cm (Figure 1A, 1B). Calibrate the colors of the images by using the manufacturer-provided software programme (Spyderchekr 24; Datacolor, Trenton, NJ, USA)
2. Extract the CIE L, a* and b* values from the prosthesis and the healthy ear and document the values which will serve as the baseline. For this technique, the color difference between healthy and prosthetic ear considered as $\Delta E = 0$, which means no color difference was present at the time of delivery
3. Extract the colors using a photo editing software programme (Adobe Photoshop Lightroom CC; Adobe, San Jose, California, USA) using the following commands:

   Import image **>** Select *'developer'* tool **>** Select *'eyedropper tool'* **>** Select *'18% grey color'* **>** Report the mean L*, a*, b* values by recording them at 3-5 different points on the photographed silicone prosthesis

Steps implemented during follow-up through teledentistry

1. Use a photo editing software programme (Adobe Photoshop Lightroom CC; Adobe, San Jose, California, USA) to generate a virtual 18% middle-grey reference card using the following commands: Select *'file'* **>** Select '*new'* **>** Select '*height* (4 inches), *width* (6 inches) and *resolution* (300 ppi)' **>** Select '*RGB*' > Select *'create'* > Select '*edit'* > Select *'fill'* > Select *'contents'* > Select *'50% grey'* > save the image as *'PNG'* format (Figure 2A, 2B, 2C, 2D)

Provide the custom-made virtual grey card to the patient via email[8] and ask the patient to download and save it to a personal computer. Instruct the patient to use the grey card as the virtual background in a teleconferencing app (ZOOM; San Jose, California, USA) using the following commands: Select the superscripted arrow on *'stop video'* tool **>** Select *'choose virtual background'* **>** Select *'add image'* icon **>** Import '*custom made 18% grey image*' **>** Select *'cross'* button

Ask the patient to position the silicone prosthesis perpendicularly at an approximate distance of 50 cm from the computer webcam and capture a still image of the prosthesis against the provided grey background. Afterwards, the patient should follow the same protocol for their opposite healthy ear and email the photographed images (Figure 3A, 3B).

To minimize variations, the following steps need to be maintained; 1) distance between the prosthesis/healthy ear and the webcam should remain constant throughout the procedure; 2) the background needs to be matte and in solid color to avoid unwanted reflections; 3) wearing the same clothing as at the time of prosthesis delivery is preferrable

Steps for color analysis

1. Use photo editing software programme (Adobe Lightroom Classic CC; Adobe, San Jose, California, USA) to correct the colors using the grey background and extract the L, a* and b* values using the following commands:

   Import image **>** Select *'developer'* tool **>** Select *'eyedropper tool'* **>** Select *'18% grey color'* **>** Report the mean L*, a*and b* values by recording them at 3-5 different points on the photographed silicone prosthesis (Figure 4A, 4B).

2. Measure the color variations by extracting the L, a* and b* values from the prosthesis and healthy ear images and compare these values with the previously extracted color values (prior delivery) to evaluate the 'Euclidian' color differences (i.e., ΔE) by employing following equation:

   $$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

   Here, ΔL= (L* value of the prosthesis – L* value of the reference healthy ear); Δa = (a* value of the prosthesis – a* value of the reference healthy ear); Δb = (b* value of the prosthesis – b* value of the reference healthy ear)

DISCUSSION

Teledentistry combines telecommunication technology with dental care, where professionals can assess and educate patients regarding oral health and reach patients in remote areas with limited access to specialized dental facilities.[2] The color analyses carried out via photographic methods relied on the global CIE L, a* and b* color standard (where, L refers to lightness, a* and b* refer to color characteristics in which a* is color within the red to green axis and b* is yellow to blue axis) as established by the International Commission on Illumination (CIE).[3] Images are susceptible to factors including camera focus, picture background, ambient light, and the distance between the specimen and camera lens.[4,9] Neutralizing ambient light-induced variations require extensive color corrections (i.e., balancing the extra global colors) by using single color calibration cards (18% grey cards) or professional multi-color calibration systems (color charts) photographed within the same frame as the subject.[10] However, these cards are expensive, not readily available within the clinics, and can weather under UV exposure in harsh climates.[11] To assist the color analysis procedure, the current technique used a customized 18% grey background instead of physical calibration cards. A virtual background predominantly allows the camera to maintain its focus on the subject therefore the photographs are not affected by the metameric properties of the objects in the background. When the present technique was statistically compared to alternative methods (i.e., webcam photograph of prosthesis alongside Macbeth color chart, webcam photograph of prosthesis with physical grey card, screenshot of prosthesis alongside Macbeth color chart inside teleconferencing application, screenshot of prosthesis alongside physical grey card inside teleconferencing application, smartphone image of prosthesis with Macbeth color chart, smartphone image of prosthesis with grey card) of color evaluation at three different times of the day, it was found that a 18% grey reference background remained consistent across different times of a day (Table 1).

Different light spectrums are emitted at different times of the day[12] and colors are mainly understood as visually indistinguishable metameric lights represented by their spectral power distribution (i.e., illumination per unit wavelength).[13] The light spectrum is measured based on its warmth (reddish) to cool (bluish) spectrum in Kelvin (K) using a numerical system termed color temperature. A luminosity indexing application (LightMeter; Trajkovski Labs)[14] demonstrated that at 1pm the color temperature was 6000K, whereas at 9am and 5pm the color temperatures dropped by 3500K. Photographs in the current report were taken across the 3 times of the day (9am, 1pm, and 5pm) using different camera hardware and variations were estimated by the Euclidean color differences (ΔE) formula. Studies that held ΔE as a methodological standard[11,15,16] have mentioned that color differences (ΔE) of silicone elastomer at 4.4 was clinically acceptable to the naked eye while digital color analysis could see variations of up to 15.13. The current study utilising the described technique demonstrated acceptable color variations (Table 1) along with consistent L, a* and b* values across different times of the day (Table 2). The technique demonstrated initial capability in distinguishing color changes in the tested auricular prosthesis and may be used by practitioners to make an immediate recommendation on a prosthesis' physical color.[17]

Although the outcome of this technique demonstrated great promise, there were some limitations. Some devices have lower quality in-built webcams that are prone to graining, pixilation (i.e., blurriness due to visibility of individual pixels in dimly lit conditions), screen tearing (i.e., visual artefacts when the software and camera are out of sync with the display) and can produce slightly different color values with the same settings. In such situations, an external webcam is advisable. The current technique was limited to a single personal computer (Acer Spin 3; Acer, New Taipei, Taiwan) and should be evaluated across a range of other devices and clinical cases to ensure reproducibility. Moreover, the present technique solely assessed the colors of the prosthesis without emphasizing the reference colors (i.e., healthy ear), hence further studies are needed evaluating different skin colors using the same technique. While capturing images for the current technique, it was seen that the video background kept auto calibrating itself as the subject switched from prosthesis to healthy ear predisposing to outcome variations. The technique also requires patients to have access to a computer and be computer literate.

SUMMARY

The present technique utilising an 18% middle-grey virtual background neutralized inappropriate color values from skin-colored prosthetic images captured by a computer webcam during teleconferencing. This proposed method is a viable, cost-effective alternative for evaluating color changes of auricular prostheses that can be used to guide the need for replacement utilizing a teledentistry platform.

"**Acknowledgement:** None

Conflicting Interest: None

Authors contributions:

Equal contributions. All authors approved the final version of the article.

Ethical Policy and Institutional Review Board Statement: Not applicable

Table 1: Euclidean Color changes (ΔE) of auricular prosthesis for different methods of color evaluation across time of day

Methods Compared	Healthy Ear ΔE	9am ΔE	1pm ΔE	5pm ΔE
Image of 18% grey reference card as virtual background	**0**	**5.27**	**3.54**	**1.71**
Webcam photograph of prosthesis alongside Macbeth color chart	0	5.13	7.80	3.18
Webcam photograph of prosthesis with physical grey card	0	4.22	1.42	3.47
Screenshot of prosthesis alongside Macbeth color chart inside teleconferencing application	0	6.16	7.30	4.90
Screenshot of prosthesis alongside physical grey card inside teleconferencing application	0	1.60	7.85	3.84
Smartphone image of prosthesis with Macbeth color chart	0	5.55	3.15	3.42
Smartphone image of prosthesis with grey card	0	6.39	5.55	1.42

* Compared to healthy ear. Lower ΔE values indicate less color variations. ΔE = 0 indicates no color change

Table 2: Analysis of variance of CIE L, a* and b* between 18% grey card as virtual background and the other evaluation methods

L value				
	Sum of squares (df)	**Mean squares**	**F stat**	***P****
Between groups	433.106 (6)	72.184	5.596	.004*[a]
Within groups	180.587 (14)	12.899		
Total	613.692 (20)			
a value*				

L value				
	Sum of squares (df)	**Mean squares**	**F stat**	***P****
	Sum of squares (df)	**Mean squares**	**F stat**	***P****					
Between groups	67.186 (6)	11.198		
Within groups	60.020 (14)	4.287	2.612	.065
Total	127.206 (20)			
b* value				
	Sum of squares (df)	**Mean squares**	**F stat**	***P****
Between groups	280.931 (6)	46.822		
Within groups	161.607 (14)	11.543	4.056	.014*[b]
Total	442.538 (20)			

*Significant < .05; df = degree of freedom

One way ANOVA: All parametric assumptions met. Shapiro Wilk test not significant (*P* > .05)

[a] Post-hoc (Tukey's) test for L: 18% grey card as virtual background produced no significant differences (*P* > .05) against other groups. Significant differences (*P* < .05) were seen between webcam images of Macbeth color chart and smartphone camera images

[b] Post-hoc (Tukey's) test for b*: 18% grey card as virtual background produced no significant differences (*P* > .05) against other groups. Significant differences (*P* < .05) were observed between Screenshots of Macbeth color chart and smartphone camera images of physical grey cards

FIGURE LEGENDS

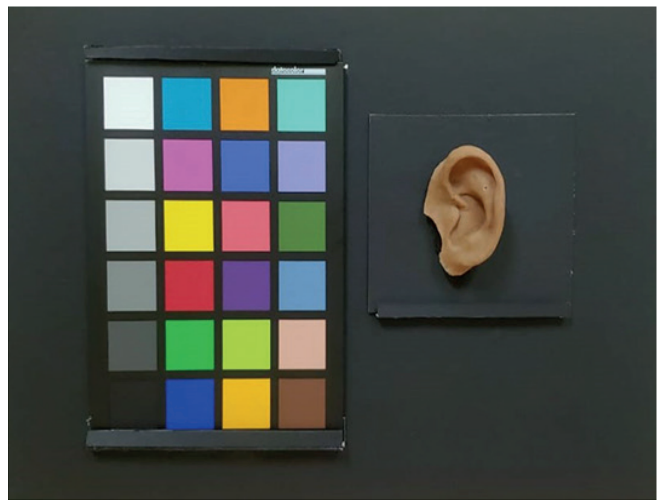
Figure 1: Images have been taken proprietary to the prosthesis delivery, A. Prosthesis with Macbeth color chart, B. Patient's healthy ear along with the Macbeth color chart

Figure 2: Fabrication of 18% grey card via photo-editing software, A. Grey fill option was located within the photo-editing software, B. 50% middle grey parameter was selected, C. The virtual 18% grey image cared was exported in PNG file format, D. Custom 18% middle grey card to be used as a virtual background

Figure 3: A. Patient prosthesis stationed in front of the virtual 18% grey background, B. Patient healthy ear (opposite) stationed in front of the virtual 18% grey background

Figure 4: Color calibration of the prosthesis according to 18% grey background, A. An eyedropper tool was used to isolate the color coordinates for the 18% grey background and adjust settings for the scene according to the background, B. The L, a* and b* values were evaluated on the color-corrected prosthesis at several locations and a mean value was used to evaluate prosthetic color

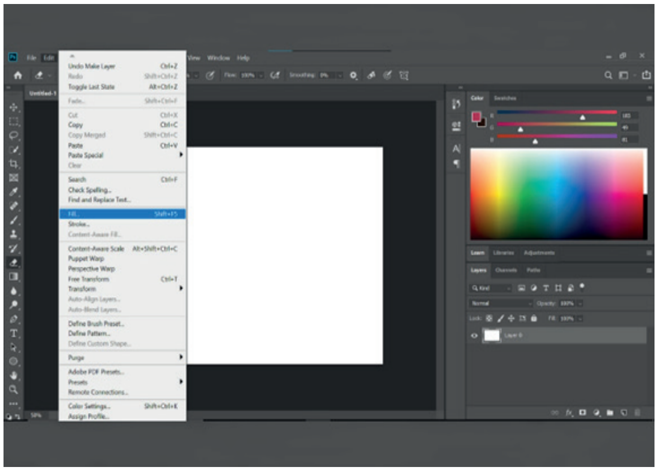
Figure 1: Images have been taken proprietary to the prosthesis delivery



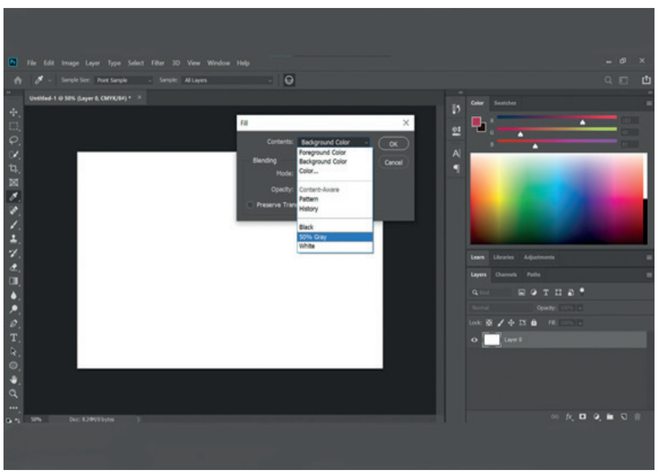
1A. Prosthesis with Macbeth color chart

1B. Patient's healthy ear along with the Macbeth color chart

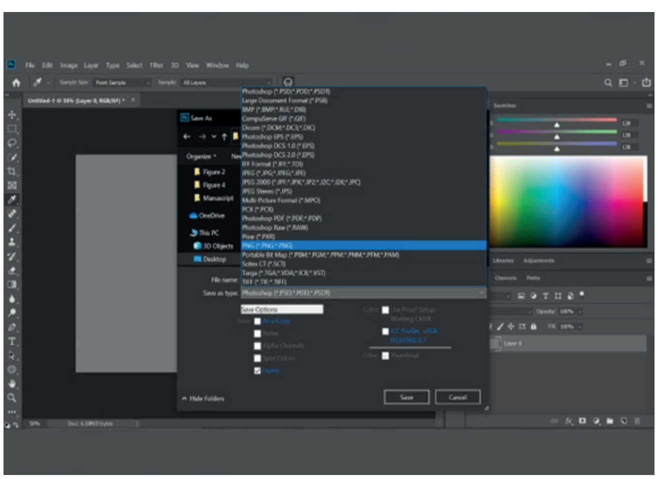
Figure 2: Fabrication of 18% grey card via photo-editing software



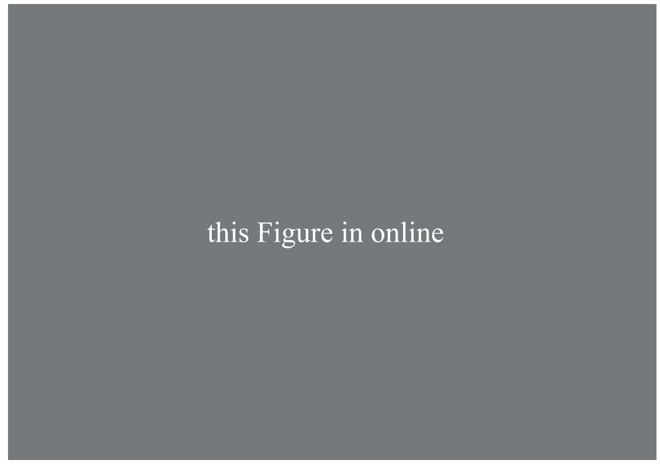
2A. Grey fill option was located within the photo-editing software



2B. 50% middle grey parameter was selected



2C. The virtual 18% grey image cared was exported in PNG file format



2D. Custom 18% middle-grey card to be used as a virtual background

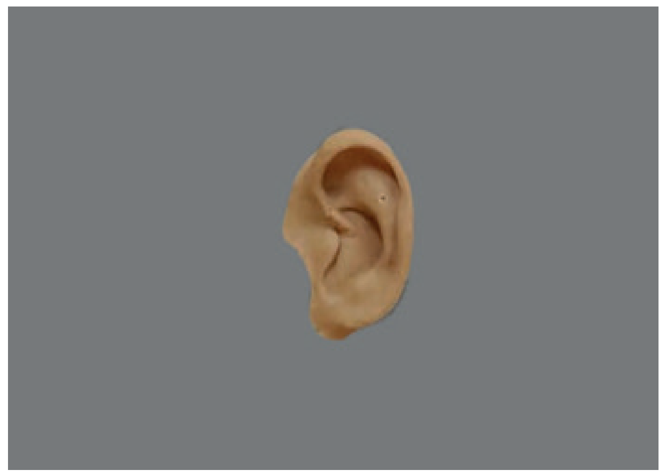
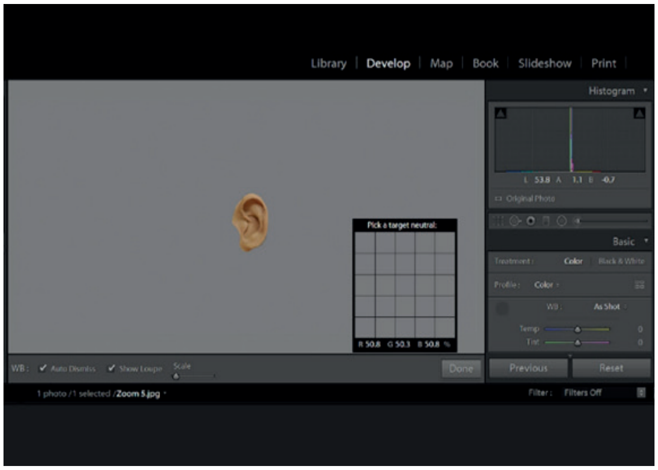


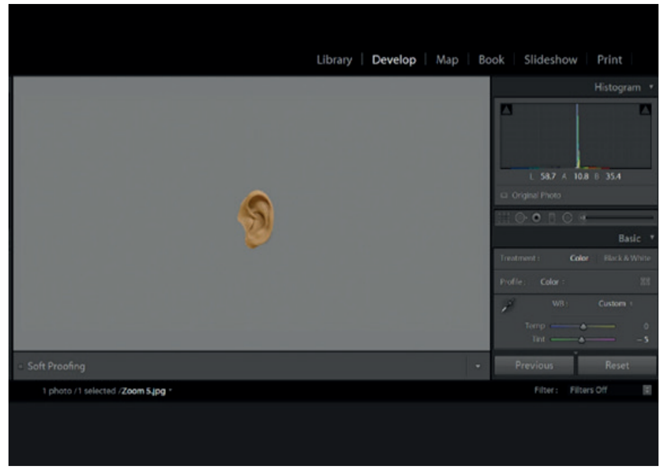
Figure 3: 3 A. Patient prosthesis stationed in front of the virtual 18% grey background

3B. Patient healthy ear (Opposite) stationed in front of the virtual 18% grey background

Figure 4: Color calibration of the prosthesis according to 18% grey background



4A. An eyedropper tool was used to isolate the color coordinates for the 18% grey background and adjust settings for the scene according to the background



4B. The LAB values were evaluated on the color-corrected prosthesis at several locations and a mean value was used to evaluate prosthetic color

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