THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Coverage error and shade-match accuracy in three ceramic gingival systems

Alejandra Díaz Hernández, DDS,[a] Alicia Celemín Viñuela, DDS, PhD,[b] Miguel Gómez-Polo, DDS, PhD,[c] Ana María Martín Casado, DDS, PhD,[d] and Cristina Gómez-Polo, DDS, PhD[e]

ABSTRACT

Statement of problem. Research into the coverage error (CE) of gingival systems that have been expanded by using ceramic specimens created by mixing basic colors is lacking.

Purpose. The purpose of this in vitro study was to compare the CEs of 3 ceramic gingival color systems that have been expanded with basic-color mixtures from a sample of 360 White participants and to classify the participants according to the accuracy of the shade match achieved with each system.

Material and methods. L*a*b* color coordinates were recorded in 3 zones of attached gingiva for 360 White participants with healthy gingival tissue (187 men and 173 women). The CEs were calculated for 3 ceramic gingival systems that had been expanded with specimens obtained by mixing the basic colors in consecutive order, the color percentages in each mixture having been altered by 10% increments. The systems were Heraceram (Kulzer GmbH) (n=51); Vita VM9 (Vita-Zahnfabrik) (n=41); and IPS Style (Ivoclar AG) (n=41). The participants were classified into 3 groups according to how well the selected shade matched their gingival color (excellent, acceptable, or poor). The data were analyzed using a 1-way ANOVA with a randomized block design and the homogeneity of proportions test (α=.05).

Results. Statistically significant differences were found between the CEs of the 3 expanded gingival systems in the 3 zones where gingival color was measured (P<.001). The expanded Heraceram system had the smallest CE (ΔE_{00}: minimum 2.66 in the middle zone and maximum 2.95 at the mucogingival line). In the 3 gingival zones, the expanded IPS Style system produced the largest percentage of participants with a poor shade match (ΔE_{00}: minimum 71.4% at the mucogingival line and maximum 75.8% at the free gingival margin), while the expanded Heraceram system had the lowest percentage of participants with a poor shade match (ΔE_{00}: minimum 33.3% in the middle zone and maximum 41.7% at the mucogingival line).

Conclusions. The CEs calculated for the expanded Vita VM9 and IPS Style ceramic gingival color systems exceeded the clinical acceptability thresholds in the 3 zones examined. According to the ΔE_{00} formula, the gingival color of at least 33% of participants matched poorly with the expanded systems studied. (J Prosthet Dent 2025;133:264-272)

When clinicians need to correct gingival defects and bone atrophy, prosthetic restorations, together with periodontal surgery, are a therapeutic option for achieving optimal gingival esthetics.[1–7] The challenge of successfully reproducing gingival color in dentistry has been well documented, and significant progress remains to be made in the field of gingival color.[8–13] The complex characteristics of gingival tissue (translucency, thickness, biotype, texture, and nonuniform color),[11,14] the inherent errors in each observer's subjective visual perception,[15–18] and the limited number of physical shade tabs provided by each manufacturer make gingival color matching particularly challenging. Dental laboratory technicians produce indirect restorations using dental[19–21] and/or gingival material that corresponds to the color selected using the physical tabs in each gingival shade guide. Given that a standard for gingival shade guides is lacking,[11] the visual color comparison between physical shade tabs and the adjacent gingival tissue has been conducted using each manufacturer's specific shade guide. The basic colors of the gingival physical shade

Study was conducted within the Research Group "Avances en Salud Oral" (Advances in Oral Health) of the University of Salamanca, Salamanca, Spain.
Declarations of interest: none.
[a]PhD student, Department of Dentistry, School of Medicine, University Complutense of Madrid, Madrid, Spain.
[b]Research Professor, Department of Dentistry, School of Medicine, University Complutense of Madrid, Madrid, Spain.
[c]Full Professor, Department of Dentistry, School of Medicine, University Complutense of Madrid, Madrid, Spain.
[d]Full Professor, Department of Statistics, School of Medicine, University of Salamanca, Salamanca, Spain.
[e]Full Professor, Department of Surgery, School of Medicine, University of Salamanca, Salamanca, Spain.

Clinical Implications

The colors provided by the expanded ceramic gingival systems increase chromatic variability, thereby decreasing errors in the coverage of participants' gingival color. However, the resulting CEs were still not satisfactory for all the systems tested. The systems are therefore unable to achieve an accurate match between the color of the natural gingiva and the adjacent ceramic gingiva in a large proportion of the White population.

tabs have been mixed in controlled proportions to produce new ceramic specimens and thereby increase gingival color variability.[22,23] These expanded gingival colors can aid in the search for methods of decreasing the coverage error (CE) of gingival shade guides,[24] an important goal since it makes accurate shade matching more likely.

Most spectrophotometers used in dentistry are not able to measure gingival color, and those that can record gingival color coordinates are not able to convert the information into physical shade tabs since the 2 methods have yet to be aligned. To be able to perform valid subjective color selection for gingival tissue, it is therefore important to create internationally standardized gingival guides that become widely used. To ensure the validity of these gingival shade guides, the physical shade tabs should be ordered according to the 3 components of color, should be distributed homogeneously in the color space, taking into account the gingival perceptibility and acceptability thresholds,[25] and should cover the natural gingival color space.[26–32] A shade guide should perform satisfactorily in shade matching, meaning that it needs to have a relatively low CE (the mean of the minimum color differences between its shade tabs and participant gingiva).[30,33–35] One way to meet these requirements is to study the color coordinates of ceramic gingival specimens produced from mixtures of the basic colors provided by the various manufacturers and compare them with the color coordinates of natural gingiva in people of different ethnicities.

A range of studies[8,9,14,24,25,30,34,36] have explored the CE of gingival shade guides with relatively unsatisfactory results. More detailed research should focus on new gingival colors that can move the field closer to recreating the wide chromatic variability of natural gingiva, thereby helping indirect restorations replicate the adjacent gingival tissue.[22] Perceptibility and acceptability thresholds have been established to facilitate clinical assessments of color based on color-difference values. The 50:50% perceptibility threshold refers to a scenario in which 50% of observers perceive a color difference between 2 objects, whereas the other 50% do not. A color difference considered acceptable by 50% of observers constitutes the 50:50% acceptability threshold.[22,37,38] Few studies[22,23] have determined how using color samples obtained by mixing basic gingival colors improves the performance of the materials used to replace gingival tissue.

To quantify color, the Commission Internationale de l'Éclairage (CIE) produced a chromatic model in 1976, aiming to describe all the colors the human eye can perceive. The model used 3 color coordinates, representing lightness – L* (the color is black when L*=0, and white when L*=100), the green to red scale – a* (negative values indicate green, and positive values indicate red), and the blue to yellow scale – b* (negative values indicate blue, and positive values indicate yellow). The 2 formulae most often used to quantify the difference between 2 colors in dentistry have been[39] the Euclidean formula ($\Delta E_{ab}=[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$) and the CIEDE2000 formula ($\Delta E_{00}=\left[\left(\frac{\Delta L'}{K_L S_L}\right)^2+\left(\frac{\Delta C'}{K_C S_C}\right)^2+\left(\frac{\Delta H'}{K_H S_H}\right)^2+R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)\right]^{1/2}$). While the CIEDE2000 formula involves more complex calculations, it has the advantage of correlating more closely with human visual perception.[40–43]

The first objective of this study was to determine and compare the CEs of 3 ceramic gingival color systems (Heraceram; Kulzer GmbH, Vita VM9; Vita Zahnfabrik, IPS System; Ivoclar AG) when expanded with basic-color mixtures (the proportions of each mixture being altered by 10% increments) for a sample of 360 White participants. The study's second objective was to classify the participants according to the accuracy of the shade match achieved using each expanded ceramic gingival color system (categorizing matches as excellent, acceptable, or poor) and compare the percentages of participants in each shade-match category for the 3 expanded color systems. The null hypotheses were that no statistically significant differences would be found between the CEs of the 3 ceramic gingival systems, as expanded with basic-color mixtures, and that no statistically significant differences would be found between the percentages of participants in each category of shade-match accuracy for the 3 expanded color systems.

MATERIAL AND METHODS

A total of 360 White individuals with healthy gingival tissue (187 men and 173 women) aged between 18 and 92 years participated in this study, each with healthy maxillary central incisors. All participants signed an informed consent form, and the study was approved by the Institutional Bioethics Committee. L*, a* and b* color coordinates were recorded in 3 zones of the participants' attached gingiva (the mucogingival line, middle zone, and free gingival margin) using a spectrophotometer (SpectroShade Micro; MHT Optic Research AG). Table 1 shows the primary indices describing the gingival color of the participants in the study.

Table 1. Indices describing L*, a*, and b* coordinates of 360 participants in each zone of attached gingiva

	Mucogingival Line			Middle Zone			Free Gingival Margin		
	L*	a*	b*	L*	a*	b*	L*	a*	b*
Mean	49.6	23.6	14.8	50.6	24.2	15.2	50.3	23.8	14.8
Standard deviation	6.2	4.2	2.6	5.7	4.1	2.8	5.9	4.4	2.6
Minimum	28.3	11.2	6.9	31.5	12.1	8.6	30.1	11.1	7.4
Maximum	65.4	36.6	25.2	64.2	37.2	24.9	63.5	36.9	24.8

The L*, a*, and b* coordinates were recorded 3 times with the same spectrophotometer for each ceramic specimen to obtain the mean values. Daylight-colored fluorescent tubes (TLD 95/65; Philips) and the same dental cabinet were used for all color measurements, and the color of all ceramic specimens was measured against a neutral gray background. The operator (C.G.P.) held the optic handpiece at 90 degrees to the surface of the ceramic specimens or attached gingiva. The spectrophotometer (SpectroShade Micro) measured the complete tooth, determining its color by producing and analyzing digital images. Its optical configuration was 45 degrees of illumination and 0 of degrees observation (45/0) according to the manufacturer.

The study used 3 ceramic gingival color systems: the Heraceram system (Kulzer GmbH) (HK), with 6 basic colors (G2, G4, G5, G6, G7, and G8); the Vita VM9 system (Vita-Zahnfabrik) (VZ), with 5 basic colors (G1, G2, G3, G4, and G5); and the IPS Style system (Ivoclar AG) (IV), with 5 basic colors (G1, G2, G3, G4, and G5). To expand these systems, porcelain specimens were made by mixing the basic colors and following the numerical order used by the manufacturers. All specimens (basic colors and mixtures) were produced by using a silicone template (New Architect wax-up assistant anterior, Form B, Large; SmileLine Europe GmbH) measuring approximately 10.6×61.6×33.2 mm in a similar manner to previous research.[22,43,44]

The percentage of each basic color was altered by 10% with each new mixture using metric scoops (Renfert GmbH) to measure the ceramic powder (Fig. 1); for example, 90% of G1 was mixed with 10% of G2, 80% of G1 with 20% of G2, and so on until mixtures containing 10% of G1 and 90% of G2 were produced. The same procedure was followed for all subsequent basic-color combinations in consecutive order (up to G4-G5 for the VZ and IV systems and G7-G8 for the HK system). At the end of this process, the expanded HK system contained 6 basic colors and 45 mixed-color specimens, making a total of 51; the expanded VZ system contained 5 basic colors and 36 mixed-color specimens, making a total of 41; and the expanded IV system contained 5 basic colors and 36 mixed-color specimens, making a total of 41. The total number of ceramic gingival color specimens analyzed was 133. The color coordinates of the specimens in the 3 expanded ceramic color systems were recorded 3 times using the spectrophotometer, as shown in Table 2. These coordinates are represented in Figure 2 together with the L* a* b* coordinates of the participants' gingiva.

For each expanded system and in each of the 3 zones of attached gingiva, the porcelain specimen with the smallest color difference in relation to the attached gingiva was identified for each participant, and the minimum color

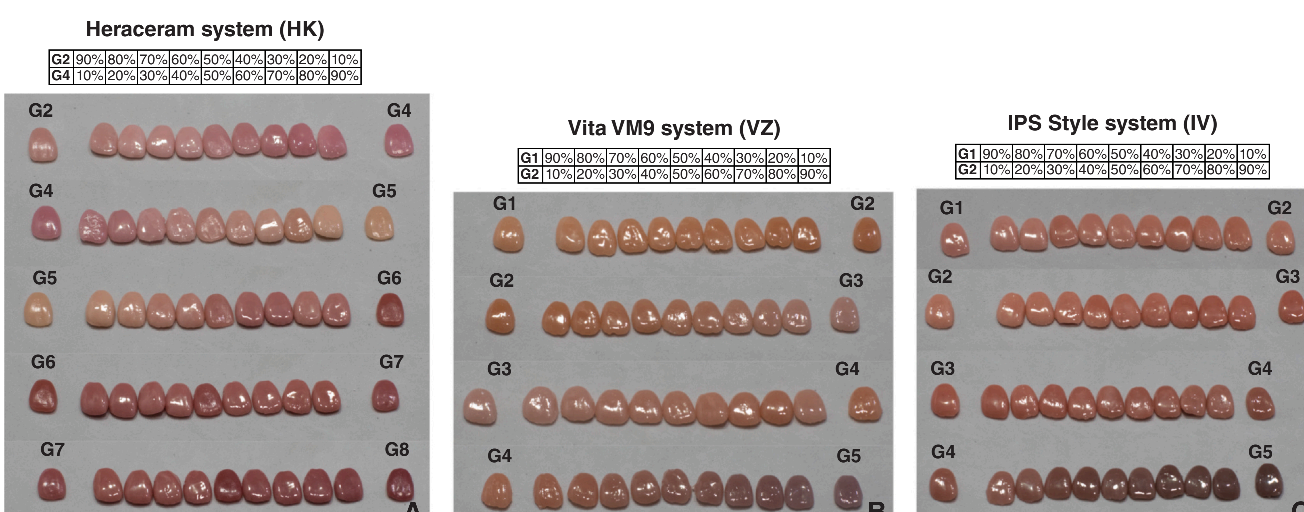

Figure 1. Ceramic gingival specimens in three color systems expanded with basic-color mixtures (altered by 10% increments). A, Heraceram (Kulzer GmbH). B, Vita VM9 (Vita Zanhfabrik). C, IPS Style (Ivoclar AG).

Table 2. Means (standard deviation) of L*, a*, and b* coordinates of porcelain specimens in three color systems expanded by using methodology described

HERACERAM - Kulzer GmbH (HK)				VITA VM9 - Vita-Zahnfabrik (VZ)				IPS STYLE - Ivoclar AG (IV)			
	L*	a*	b*		L*	a*	b*		L*	a*	b*
G2	60.1 (0.1)	18.8 (0.2)	11.8 (0.1)	G1	60.4 (0.3)	22.9 (0.3)	14.9 (0.2)	G1	62.3 (0.3)	17.4 (0.4)	23.6 (0.4)
90G2+10G4	60.2 (0.1)	16.4 (0.2)	9.4 (0.1)	90G1+10G2	62.6 (0.3)	21.3 (0.3)	15.1 (0.2)	90G1+10G2	63.0 (0.0)	17.0 (0.3)	23.6 (0.3)
80G2+20G4	65.0 (0.1)	18.0 (0.2)	10.1 (0.2)	80G1+20G2	62.8 (0.2)	21.5 (0.2)	15.8 (0.1)	80G1+20G2	60.9 (0.1)	18.2 (0.2)	23.9 (0.1)
70G2+30G4	64.3 (0.2)	19.4 (0.3)	9.9 (0.1)	70G1+30G2	57.8 (0.1)	24.5 (0.2)	17.5 (0.1)	70G1+30G2	59.4 (0.1)	19.6 (0.1)	24.3 (0.1)
60G2+40G4	64.6 (0.4)	19.2 (0.4)	9.1 (0.2)	60G1+40G2	61.9 (0.1)	23.2 (0.1)	12.5 (0.1)	60G1+40G2	60.3 (0.2)	19.3 (0.1)	24.6 (0.2)
50G2+50G4	57.4 (0.1)	22.6 (0.2)	8.4 (0.3)	50G1+50G2	62.2 (0.2)	23.2 (0.1)	18.3 (0.1)	50G1+50G2	59.1 (0.3)	19.3 (0.1)	24.1 (0.2)
40G2+60G4	57.2 (0.5)	23.1 (1.0)	8.4 (0.3)	40G1+60G2	59.8 (0.7)	24.8 (0.6)	19.4 (0.4)	40G1+60G2	58.4 (0.1)	19.3 (0.1)	24.4 (0.1)
30G2+70G4	55.9 (0.3)	24.0 (0.3)	7.4 (0.2)	30G1+70G2	58.2 (0.1)	25.5 (0.1)	19.8 (0.2)	30G1+70G2	58.8 (0.1)	19.4 (0.4)	23.9 (0.2)
20G2+80G4	55.0 (0.1)	25.0 (0.3)	6.4 (0.1)	20G1+80G2	59.2 (0.2)	25.2 (0.4)	20.3 (0.3)	20G1+80G2	56.2 (0.1)	20.5 (0.3)	24.9 (0.2)
10G2+90G4	57.4 (0.3)	24.0 (0.3)	6.2 (0.1)	10G1+90G2	61.5 (0.4)	23.5 (0.7)	19.8 (0.6)	10G1+90G2	54.5 (0.1)	21.5 (0.1)	25.7 (0.2)
G4	57.7 (0.3)	23.9 (0.3)	6.3 (0.1)	G2	60.5 (0.1)	24.9 (0.1)	20.1 (0.1)	G2	54.5 (0.1)	21.3 (0.1)	24.9 (0.2)
90G4+10G5	53.6 (0.1)	25.8 (0.3)	5.3 (0.1)	90G2+10G3	60.0 (0.2)	25.1 (0.1)	19.8 (0.1)	90G2+10G3	56.0 (0.2)	20.5 (0.5)	24.2 (0.6)
80G4+20G5	58.2 (0.3)	22.9 (0.1)	8.6 (0.1)	80G2+20G3	55.5 (0.0)	27.9 (0.4)	20.9 (0.2)	80G2+20G3	56.3 (0.1)	23.3 (0.2)	23.1 (0.1)
70G4+30G5	61.8 (0.3)	19.7 (0.1)	9.3 (0.1)	70G2+30G3	56.2 (0.1)	27.9 (0.4)	20.7 (0.3)	70G2+30G3	56.7 (0.0)	19.3 (0.1)	22.0 (0.2)
60G4+20G5	63.9 (0.2)	18.4 (0.3)	10.7 (0.2)	60G2+40G3	58.2 (0.1)	27.5 (0.2)	19.6 (0.1)	60G2+40G3	56.7 (0.3)	18.9 (0.3)	20.6 (0.3)
50G4+50G5	58.4 (0.3)	19.0 (0.2)	12.8 (0.2)	50G2+50G3	57.0 (0.1)	28.1 (0.3)	19.8 (0.3)	50G2+50G3	57.6 (0.2)	17.9 (0.1)	18.8 (0.1)
40G4+60G5	63.5 (0.1)	17.1 (0.1)	13.9 (0.1)	40G2+60G3	54.5 (0.1)	29.6 (0.4)	20.3 (0.3)	40G2+60G3	57.0 (0.1)	17.6 (0.1)	17.7 (0.1)
30G4+70G5	65.2 (0.1)	16.2 (0.1)	15.1 (0.1)	30G2+70G3	54.0 (0.1)	30.3 (0.2)	20.7 (0.2)	30G2+70G3	58.7 (0.2)	16.0 (0.2)	15.8 (0.1)
20G4+80G5	59.7 (0.2)	17.1 (0.1)	16.6 (0.1)	20G2+80G3	55.6 (0.1)	28.9 (0.1)	19.4 (0.1)	20G2+80G3	58.2 (0.1)	16.2 (0.1)	15.4 (0.1)
10G4+90G5	67.3 (0.2)	13.6 (0.1)	17.5 (0.2)	10G2+90G3	53.1 (0.2)	30.4 (0.1)	20.0 (0.1)	10G2+90G3	59.5 (0.1)	15.2 (0.2)	14.2 (0.1)
G5	63.3 (0.2)	13.9 (0.3)	20.8 (0.3)	G3	53.3 (0.1)	29.9 (0.1)	19.7 (0.1)	G3	60.0 (0.4)	14.8 (0.1)	12.3 (0.0)
90G5+10G6	66.3 (0.2)	15.2 (0.1)	18.3 (0.1)	90G3+10G4	54.8 (0.1)	29.1 (0.4)	19.5 (0.3)	90G3+10G4	59.1 (0.2)	15.3 (0.3)	13.3 (0.2)
80G5+20G6	64.2 (0.3)	16.3 (0.2)	16.4 (0.2)	80G3+20G4	50.8 (0.1)	29.6 (0.3)	19.9 (0.2)	80G3+20G4	59.0 (0.1)	16.3 (0.2)	14.5 (0.1)
70G5+30G6	60.8 (0.3)	19.4 (0.4)	15.6 (0.4)	70G3+30G4	53.4 (0.2)	27.1 (0.2)	18.3 (0.1)	70G3+30G4	58.1 (0.1)	17.3 (0.2)	15.3 (0.1)
60G5+40G6	61.0 (0.1)	20.4 (0.2)	15.1 (0.1)	60G3+40G4	53.5 (0.1)	25.3 (0.3)	17.2 (0.1)	60G3+40G4	57.6 (0.1)	17.9 (0.1)	16.0 (0.1)
50G5+50G6	52.7 (0.2)	25.1 (0.2)	14.3 (0.1)	50G3+50G4	51.6 (0.2)	26.0 (0.2)	17.5 (0.1)	50G3+50G4	57.2 (0.1)	18.8 (0.1)	16.6 (0.1)
40G5+60G6	55.1 (0.2)	25.9 (0.2)	12.4 (0.1)	40G3+60G4	52.5 (0.4)	25.0 (0.3)	17.0 (0.1)	40G3+60G4	57.4 (0.1)	18.8 (0.1)	17.0 (0.1)
30G5+70G6	54.0 (0.1)	26.9 (0.1)	11.8 (0.2)	30G3+70G4	53.3 (0.1)	25.4 (0.1)	17.8 (0.1)	30G3+70G4	55.5 (0.1)	16.7 (0.2)	18.0 (0.1)
20G5+80G6	57.8 (0.2)	23.5 (0.2)	14.0 (0.1)	20G3+80G4	53.4 (0.2)	23.4 (0.2)	16.5 (0.2)	20G3+80G4	54.7 (0.2)	20.9 (0.1)	18.8 (0.1)
10G5+90G6	55.4 (0.1)	25.4 (0.3)	13.0 (0.2)	10G3+90G4	49.5 (0.1)	24.3 (0.4)	17.0 (0.3)	10G3+90G4	59.0 (0.1)	15.9 (0.2)	14.8 (0.2)
G6	45.0 (0.1)	31.3 (0.0)	11.7 (0.1)	G4	52.1 (0.1)	20.8 (0.2)	15.2 (0.2)	G4	56.2 (0.0)	21.2 (0.1)	20.5 (0.0)
90G6+10G7	50.5 (0.2)	29.0 (0.2)	12.4 (0.2)	90G4+10G5	49.2 (0.4)	19.2 (0.5)	13.9 (0.3)	90G4+10G5	53.0 (0.1)	21.0 (0.2)	22.1 (0.1)
80G6+20G7	51.1 (0.6)	28.4 (0.7)	12.4 (0.4)	80G4+20G5	48.2 (0.1)	18.5 (0.1)	13.3 (0.1)	80G4+20G5	52.1 (0.1)	20.5 (0.1)	17.8 (0.1)
70G6+30G7	52.0 (0.4)	27.6 (0.8)	12.7 (0.3)	70G4+30G5	42.9 (0.1)	17.2 (0.2)	12.0 (0.2)	70G4+30G5	51.8 (0.2)	17.7 (0.2)	14.7 (0.1)
60G6+40G7	43.7 (0.1)	30.9 (0.6)	13.7 (0.3)	60G4+40G5	45.7 (0.2)	15.7 (0.1)	11.1 (0.1)	60G4+40G5	50.8 (0.2)	17.7 (0.1)	14.1 (0.2)
50G6+50G7	51.3 (0.2)	28.9 (0.2)	13.8 (0.1)	50G4+50G5	44.7 (0.1)	14.8 (0.2)	10.4 (0.1)	50G4+50G5	49.0 (0.1)	17.4 (0.1)	12.2 (0.1)
40G6+60G7	51.4 (0.2)	28.4 (0.4)	13.1 (0.2)	40G4+60G5	41.8 (0.4)	13.5 (0.4)	9.4 (0.4)	40G4+60G5	49.6 (0.1)	16.5 (0.0)	11.4 (0.0)
30G6+70G7	50.8 (0.1)	27.9 (0.7)	14.1 (0.4)	30G4+70G5	39.7 (0.3)	13.8 (0.2)	9.8 (0.1)	30G4+70G5	47.6 (0.2)	15.7 (0.2)	9.2 (0.1)
20G6+80G7	50.3 (0.1)	29.6 (0.1)	15.2 (0.2)	20G4+80G5	40.5 (0.4)	12.8 (0.1)	9.1 (0.2)	20G4+80G5	46.2 (0.2)	15.6 (0.1)	8.4 (0.1)
10G6+90G7	42.9 (0.1)	32.9 (0.6)	17.7 (0.4)	10G4+90G5	38.5 (0.1)	12.0 (0.1)	8.7 (0.1)	10G4+90G5	46.9 (0.1)	14.1 (0.1)	6.4 (0.1)
G7	49.5 (0.3)	29.4 (0.4)	15.2 (0.2)	G5	37.8 (0.2)	11.8 (0.3)	8.1 (0.2)	G5	46.6 (0.2)	13.2 (0.2)	4.6 (0.1)
90G7+10G8	49.1 (0.2)	29.8 (0.5)	14.6 (0.3)								
80G7+20G8	49.8 (0.2)	29.0 (0.5)	13.4 (0.3)								
70G7+30G8	48.0 (0.1)	30.4 (0.1)	13.5 (0.1)								
60G7+40G8	38.4 (0.1)	32.5 (0.2)	13.8 (0.1)								
50G7+50G8	45.8 (0.2)	30.7 (0.1)	12.2 (0.1)								
40G7+60G8	45.6 (0.1)	30.6 (0.2)	11.8 (0.1)								
30G7+70G8	45.3 (0.1)	30.2 (0.2)	11.1 (0.1)								
20G7+80G8	44.1 (0.1)	30.7 (0.2)	10.9 (0.2)								
10G7+90G8	36.9 (0.2)	32.1 (0.8)	11.3 (0.3)								
G8	48.9 (0.2)	29.9 (0.6)	13.8 (0.2)								

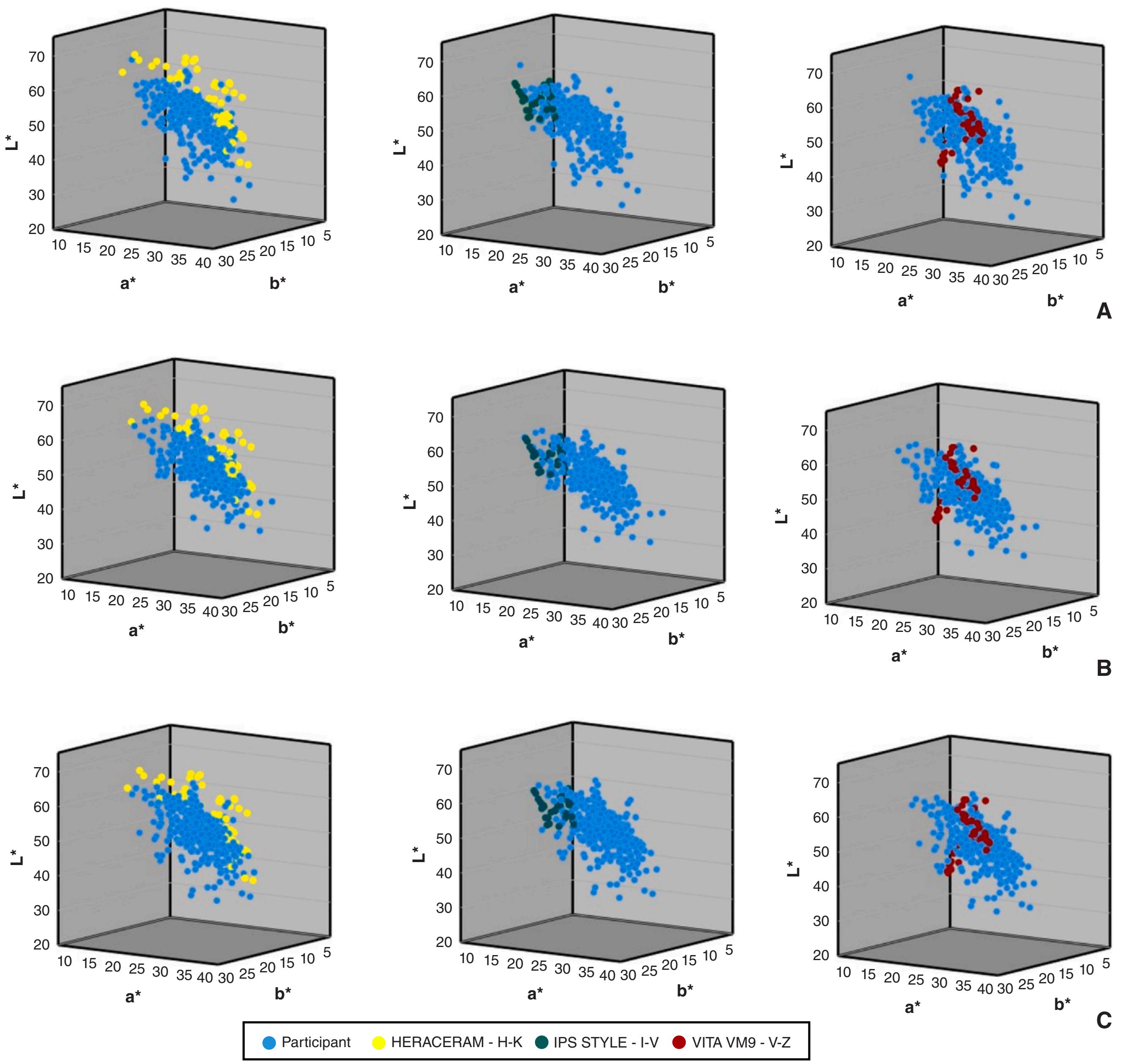

Figure 2. L*, a*, and b* coordinates of attached gingiva of participants (n=360) and of tabs in expanded color systems. A, Mucogingival line. B, Middle zone. C, Free gingival margin.

difference was recorded. Color differences were calculated using the Euclidean formula (ΔE_{ab}) and the CIEDE2000 formula (ΔE_{00}), as shown in Table 3. The CE was calculated for each color system by using the mean of the minimum color differences for all the participants.[45]

Participants were categorized according to the accuracy of the shade matches achieved as follows:[22] excellent if the minimum color difference was below or equal to the 50:50% perceptibility threshold (3.1 units for ΔEab^* and 2.1 units for ΔE_{00}); acceptable if the minimum color difference was above the 50:50% perceptibility threshold but below or equal to the 50:50% acceptability threshold (4.1 units for ΔEab^* and 2.9 units for ΔE_{00}; and poor if the minimum color difference was above the 50:50% acceptability threshold.

The CEs of the expanded systems were compared using a 1-way ANOVA with a randomized-block design (with the 360 participants as blocks).[46] This was followed, when necessary, by the Duncan multiple range test.[47] The homogeneity of proportions test was used to compare the percentage of participants in each category in the 3 expanded systems[46] (α=.05).

Table 3. Comparison of coverage errors of three expanded ceramic gingival systems using one-way ANOVA with randomized block design

	Gingival Zone	Manufacturer	Mean (CE) ±SD	F Statistic; *P*	Statistical Power*
ΔE_{ab}					
	Mucogingival line			F=75.12; *P*<.001	>.999
		Kulzer GmbH	4.46 ±2.58		
		Vita-Zahnfabrik	4.81 ±3.10		
		Ivoclar AG	6.79 ±4.34		
	Middle zone			F=96.70; *P*<.001	>.999
		Kulzer GmbH	4.04 ±2.23		
		Vita-Zahnfabrik	4.46 ±2.85		
		Ivoclar AG	6.65 ±4.11		
	Free gingival margin			F=97.59; *P*<.001	>.999
		Kulzer GmbH	4.24 ±2.58		
		Vita-Zahnfabrik	4.53 ±2.93		
		Ivoclar AG	6.80 ±4.05		
ΔE_{00}					
	Mucogingival line			F=79.18; *P*<.001	>.999
		Kulzer GmbH	2.95 ±1.65		
		Vita-Zahnfabrik	3.41 ±2.06		
		Ivoclar AG	4.63 ±2.75		
	Middle zone			F=98.18; *P*<.001	>.999
		Kulzer GmbH	2.66 ±1.46		
		Vita-Zahnfabrik	3.20 ±1.98		
		Ivoclar AG	4.46 ±2.46		
	Free gingival margin			F=108.15; *P*<.001	>.999
		Kulzer GmbH	2.77 ±1.65		
		Vita-Zahnfabrik	3.21 ±2.00		
		Ivoclar AG	4.60 ±2.48		

* Calculated using α=.05.

RESULTS

Histograms and quantile-quantile (Q-Q) graphs were produced to analyze the CEs of each zone of attached gingiva and each gingival color system. These showed that the CEs tended approximately toward statistical normality (albeit with a right-skewness due to outliers).

Table 3 shows the means (CE) and standard deviations of the color differences between the color coordinates of the participants' gingiva and the specimens that provided the best shade match for each expanded ceramic system and in each zone of attached gingiva. As Table 3 shows, the expanded HK system had the lowest CE in the 3 zones of attached gingiva according to both formulae (ΔE_{00}: CEmin 2.66 and CEmax 2.95), while the expanded IV system had the largest CE (ΔE_{00}: CEmin 4.66 and CEmax 4.63). Statistically significant differences were found between the CEs of the 3 expanded color systems in all 3 zones of attached gingiva according to both formulae (*P*<.001). In the pairwise comparison using the Duncan multiple-range test with the ΔEab* formula, no difference was identified between the CEs of the expanded HK and VZ systems (*P*>.05), but the CEs of these systems differed from those of the expanded IV system at the mucogingival line and the free gingival margin (*P*<.05). Statistically significant differences were also found between the CEs of all 3 systems in the middle zone (*P*<.05). Using the ΔE_{00} formula, the differences between the CEs of all the expanded gingival color systems were statistically significant in all 3 zones of attached gingiva (*P*<.05).

Table 4 shows the number and percentage of participants assigned to each shade-match category for the 3 expanded ceramic systems. The expanded IV system produced the largest percentages of participants for whom shade-match accuracy was poor in all 3 zones when calculated with both color-difference formulae (ΔE_{00}: min 71.4% and max 75.8%), while the expanded HK system obtained the lowest percentages of poor shade matches (ΔE_{ab}: min 40.0% and max 46.7%).

When color differences were calculated with the Euclidean formula, statistically significant differences were identified between the percentages of participants in each shade-match category for the 3 systems in all zones of attached gingiva (mucogingival line, χ^2=48.816, *P*<.001; middle zone, χ^2=72.279, *P*<.001; free gingival margin, χ^2=83.547, *P*<.001). The expanded IV system produced the least accurate results, while no statistically significant differences were found between the percentages of participants in each category at the mucogingival line and the free gingival margin for the other 2 systems (*P*>.05), although such differences were identified in the middle zone (*P*<.05). When color differences were calculated with the CIEDE2000 formula, statistically significant differences were found between the percentages of subjects in each shade-match category in all 3 zones of attached gingiva (mucogingival line, χ^2=67.234, *P*<.001; middle zone, χ^2=107.696, *P*<.001; free gingival margin, χ^2=124.938, *P*<.001). The expanded IV system was the least accurate in shade matching, and the HK system was the most accurate.

Table 4. Classification of participants according to accuracy of shade match achieved with each expanded gingival color system in each zone of attached gingiva

	Attached Gingival Zone	Manufacturer	Excellent n (%)	Acceptable n (%)	Poor n (%)
ΔE_{ab}					
	Mucogingival line				
		Kulzer GmbH	125 (34.7%)	67 (18.6%)	168 (46.7%)
		Vita-Zahnfabrik	121 (33.6%)	62 (17.2%)	177 (49.2%)
		Ivoclar AG	77 (21.4%)	31 (8.6%)	252 (70.0%)
	Middle zone				
		Kulzer GmbH	144 (40.0%)	72 (20.0%)	144 (40.0%)
		Vita-Zahnfabrik	140 (38.9%)	50 (13.9%)	170 (47.2%)
		Ivoclar AG	78 (21.7%)	31 (8.6%)	251 (69.7%)
	Free gingival margin				
		Kulzer GmbH	145 (40.3%)	66 (18.3%)	149 (41.4%)
		Vita-Zahnfabrik	140 (38.9%)	55 (15.3%)	165 (45.8%)
		Ivoclar AG	60 (16.7%)	40 (11.1%)	260 (72.2%)
ΔE_{00}					
	Mucogingival line				
		Kulzer GmbH	133 (36.9%)	77 (21.4%)	150 (41.7%)
		Vita-Zahnfabrik	115 (31.9%)	59 (16.4%)	186 (51.7%)
		Ivoclar AG	70 (19.4%)	33 (9.2%)	257 (71.4%)
	Middle zone				
		Kulzer GmbH	157 (43.6%)	83 (23.1%)	120 (33.3%)
		Vita-Zahnfabrik	123 (34.2%)	69 (19.2%)	168 (46.7%)
		Ivoclar AG	64 (17.8%)	39 (10.8%)	257 (71.4%)
	Free gingival margin				
		Kulzer GmbH	148 (41.1%)	82 (22.8%)	130 (36.1%)
		Vita-Zahnfabrik	130 (36.1%)	64 (17.8%)	166 (46.1%)
		Ivoclar AG	50 (13.9%)	37 (10.3%)	273 (75.8%)

DISCUSSION

The null hypotheses that no statistically significant differences would be found between the CEs of the 3 ceramic gingival systems as expanded with basic-color mixtures and that no statistically significant differences would be found between the percentages of participants in each category of shade-match accuracy for the 3 expanded color systems were rejected. Statistically significant differences were identified in all 3 zones of attached gingiva in a White population between the CEs of the 3 expanded ceramic gingival systems (the HK system had the smallest CE) and between the percentages of participants for whom shade-match accuracy was poor, acceptable, or excellent (the expanded HK system provided the most accurate shade matches).

The study's primary strength was the considerable expansion of the chromatic range achieved through the production of ceramic mixtures, taking the VZ and IV systems from 5 basic colors to 41 and the HK system from 6 basic colors to 51. Research on CEs in gingival color systems using a similar number of shades is lacking. Increasing the number of colors can help reduce the CE provided that the shades are chromatically comparable with the color coordinates of the population in question. Based on the color coordinates of healthy keratinized gingiva in 238 participants of 4 ethnicities,[36] Ghinea et al[34] used mathematical optimization models with cluster analysis to obtain 3, 4, 5, and 6 gingival colors, with CEs ranging from 3.1 to 3.9, calculated with ΔEab*. Using the same sample, Sarmast et al[38] evaluated 5 gingival shade guides using the ΔEab* formula: the Eclipse guide (Dentsply Sirona), with 4 tabs, obtained a CE of 5.0; the Gumy guide (Shofu), with 3 tabs, obtained a CE of 6.5; Vita VM 9 (Vita-Zahnfabrik), with 5 tabs, achieved a CE of 5.6; the IPS d.SIGN system (IV), with 5 tabs, obtained a CE of 7.3; and the IPS e.max guide (IV), with 5 tabs, achieved a CE of 7.2. With a sample of 120 that also included individuals of 4 ethnicities, Bayindir et al[8] calculated the CEs of 3 gingival color systems using the Euclidean formula: the Lucitone 199 system (4 tabs: CE=10.8), the IPS Gingiva system (10 tabs: CE=8.6), and a combination of the 2 (CE=7.9). With a similar sample, Ito et al[9] used mathematical optimization with cluster analysis to calculate a CE of 4.6 (ΔEab*) for a system with just 3 gingival shades in a White population. Recently, research conducted with 259 White participants[11] obtained CEs according to ΔEab* of 7.9 for the HeraCeram Gingiva guide (6 gingival shades) and 9.2 for the IPS d.SIGN system (5 shades).[30] Another study obtained 8 gingival shades using mathematical models, with a CE of 3.46 according to ΔEab*.[25] Grieco et al[14] analyzed several restorative materials for gingiva, excluding shade guides, and obtained CEs (ΔEab*) of between 5.89 and 10.78. In the present research, which included a significantly larger number of shade tabs than the aforementioned studies, the CEs calculated ranged from 4.04 (ΔEab*) in the middle zone to 6.80 (ΔEab*) at the free gingival margin. Using an acceptability threshold of 4.1 units for ΔEab*, the only clinically acceptable CE identified was in the middle zone for the expanded HK system; in all other locations, the CE exceeded this threshold. Some authors[22,48] have reported statistically significant differences among the color coordinates in the 3 zones of attached gingiva, although these differences were not clinically relevant.[48]

Comparing the results of the various studies is challenging given the lack of standardization regarding the number of participants and ethnicities in the sample, the device used to record color coordinates (spectroradiometer[8,9,36] or spectrophotometer[11,14,24,25,30]), or the gingival shade guides tested. Optimizing gingival shades through mathematical models has generally been shown to decrease the CE, bringing it closer to the clinical acceptability thresholds. However, the disadvantage of such models is that, unlike physical gingival shade guides, they cannot be used for subjective color selection through direct comparisons. The expanded gingival color systems used in this study provided physical specimens with which subjective color selection could be performed.

The perceptibility threshold used in this study was 3.1 units for ΔEab* and 2.1 units for ΔE00, and the acceptability threshold was 4.1 units for ΔEab* and 2.9 units for ΔE00.[22] These values correspond to the use of pink porcelain specimens in the statistical calculations, although other gingival thresholds have been published. For example, Paniz et al[13] placed the clinical acceptability threshold at ΔEab*=8.74 for gingiva, while Sailer et al[49] set it significantly lower, requiring a precision of ΔEab*=3.1 for the color difference to be clinically acceptable. Ren et al[37] published a 50:50% acceptability threshold of ΔEab*=3.7[37] in 2015, while Perez et al[41] set the threshold at ΔEab*=4.0.

Breaking the results down by zones of attached gingiva, shade matches were least accurate at the mucogingival line, followed by the free gingival margin. The most representative chromatic results according to ΔEab* were found in the middle zone, where the highest percentages of acceptable (8.6–20.0%) and excellent accuracy (21.7–40.0%) in shade matching were obtained. All the preceding interpretations of results calculated using the ΔEab* formula can be extrapolated to those calculated with the ΔE_{00} formula. To further develop the science of gingival color, future research should incorporate the gingival papillae and a wider range of pink ceramic systems. It would be beneficial to examine mixtures with different proportions of colors and other materials used in direct and indirect restorations. Exploring the visual and instrumental CEs of gingival shade guides using methods similar to those of Ruiz-López et al[50] in their research on 2 of the most popular dental shade guides would be another useful line of research.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The expanded Vita VM9 and IPS Style ceramic gingival color systems had coverage errors that exceeded the clinical acceptability threshold in all 3 zones of attached gingiva.
2. According to the ΔE_{00} formula, the color selected using the expanded ceramic systems tested provided a poor shade match when compared with the gingiva for at least 33% of the participants.

REFERENCES

1. Malament KA, Neeser S. Prosthodontic management of ridge deficiencies. *Dent Clin North Am*. 2004;48:735–744.
2. Morley J, Eubank J. Macroesthetic elements of smile design. *J Am Dent Assoc*. 2001;132:39–45.
3. Coachman C, Salama M, Garber D, Calamita M, Salama H, Cabral G. Prosthetic gingival reconstruction in a fixed partial restoration. Part 1: introduction to artificial gingival as an alternative therapy. *Int J Periodontics Restorative Dent*. 2009;29:471–477.
4. Coachman C, Salama M, Garber D, Calamita M, Salama H, Cabral G. Prosthetic gingival reconstruction in fixed partial restorations. Part 3: laboratory procedures and maintenance. *Int J Periodontics Restorative Dent*. 2010;30:19–29.
5. Priest GF, Lindke L. Gingival-colored porcelain for implant-supported prostheses in the aesthetic zone. *Pract Periodontics Aesthet Dent*. 1998;10:1231–1240.
6. Hannon SM, Colvin CJ, Zurek DJ. Selective use of gingival-toned ceramics: Case reports. *Quintessence Int*. 1994;25:233–238.
7. Durrani F, Pandey A, Singh P. Pink gingival restoration: An acceptable treatment for complex ridge defects. *J Indian Soc Periodontol*. 2022;26:609–613.
8. Bayindir F, Bayindir YZ, Gozalo-Diaz DJ, Wee AG. Coverage error of gingival shade guide systems in measuring color of attached anterior gingiva. *J Prosthet Dent*. 2009;101:46–53.
9. Ito M, Marx DB, Cheng AC, Wee AG. Proposed shade guide for attached gingiva-A pilot study. *J Prosthodont*. 2015;24:182–187.
10. Schnitzer S, Turp JC, Heydecke G. Color distribution and visual color assessment of human gingiva and mucosa: A systematic review of the literature. *Int J Prosthodont*. 2004;17:327–332.
11. Gómez-Polo C, Montero J, Gómez-Polo M, Martín Casado AM. Clinical study on natural gingival color. *Odontology*. 2019;107:80–89.
12. Heydecke G, Schnitzer S, Türp JC. The color of human gingiva and mucosa: Visual measurement and description of distribution. *Clin Oral Investig*. 2005;9:49–57.
13. Paniz G, Bressan E, Stellini E, Romeo E, Lops D. Correlation between subjective and objective evaluation of peri-implant soft tissue color. *Clin Oral Implants Res*. 2014;25:992–996.
14. Grieco PC, Da Silva JD, Ishida Y, Ishikawa-Nagai S. An in vivo spectrophotometric analysis of gingival acrylic shade guide. *Materials (Basel)*. 2021;14:1768.
15. Dagg H, O'Connell B, Claffey N, Byrne D, Gorman C. The influence of some different factors on the accuracy of shade selection. *J Oral Rehabil*. 2004;31:900–904.
16. Paul S, Peter A, Pietrobon N, Hammerle C. Visual and spectrophotometric shade analysis of human teeth. *J Dent Res*. 2002;81:578.
17. Hammad IA. Intrarater repeatability of shade selections with two shade guides. *J Prosthet Dent*. 2003;89:50–53.
18. Klemetti E, Matela AM, Haag P, Kononen M. Shade selection performed by novice dental professionals and colorimeter. *J Oral Rehabil*. 2006;33:31–35.
19. Bahannan SA, Awad MA. Effect of porcelain shade and application time on shade reproduction. *J Prosthodont*. 2018;27:227–231.
20. Montero J, Gomez-Polo C, Santos JA. Effect of ceramic veneer thickness and cement shade on the CIELAB system after bonding-an in vitro study. *Color Res Appl*. 2016;41:642–648.
21. Corciolani G, Vichi A, Louca C, Ferrari M. Color match of two different ceramic systems to selected shades of one shade guide. *J Prosthet Dent*. 2011;105:171–176.
22. Gómez-Polo C, Martín Casado AM, Gómez-Polo M, Montero J. Color thresholds of the gingival chromatic space. *J Dent*. 2020;103:103502.
23. Gómez Polo C, Montero J, Martín Casado AM. Comparison of two color-difference formulas using the Bland-Altman approach based on gingiva color space. *Odontology*. 2019;107:72–79.
24. Valente NA, Sailer I, Fehmer V, Thoma DS. Color differences between pink veneering ceramics and the human gingiva. *Int J Periodontics Restorative Dent*. 2018;38:s59–s65.

25. Gomez Polo C, Montero J, Martin Casado AM. Proposal for a gingival shade guide based on in vivo spectrophotometric measurements. *J Adv Prosthodont*. 2019;11:239–246.
26. Paravina RD. Performance assessment of dental shade guides. *J Dent*. 2009;37:e15–e20.
27. Oh WS, Koh IW, O'Brien WJ. Estimation of visual shade matching errors with 2 shade guides. *Quintessence Int*. 2009;40:833–836.
28. Li Q, Yu H, Wang YN. In vivo spectroradiometric evaluation of color matching errors among five shade guides. *J Oral Rehabil*. 2009;36:65–70.
29. Öngül D, Şermet B, Balkaya MC. Visual and instrumental evaluation of color match ability of 2 shade guides on a ceramic system. *J Prosthet Dent*. 2012;108:9–14.
30. Gómez Polo C, Montero J, Gómez Polo M, Casado AMM. Chromatic compatibility of two gingival shade guides with human keratinized gingiva. *Int J Prosthodont*. 2023;36:20–29.
31. Wee AG, Kang EY, Jere D, Beck FM. Clinical color match of porcelain visual shade-matching systems. *J Esthet Restor Dent*. 2005;17:351–357.
32. Lehmann K, Devigus A, Wentaschek S, Igiel C, Scheller H, Paravina R. Comparison of visual shade matching and electronic color measurement device. *Int J Esthet Dent*. 2017;12:396–404.
33. Amer RS, Chandrasekaran I, Johnston WM. Illuminant effect on the coverage error of a gingiva-colored composite resin shade guide. *J Prosthet Dent*. 2016;116:770–776.
34. Ghinea R, Herrera LJ, Pérez MM, Ionescu AM, Paravina RD. Gingival shade guides: colorimetric and spectral modeling. *J Esthet Restor Dent*. 2018;30:E31–E38.
35. Farhad Tabatabaian F, Saleh Khezri A, AmirHossein Ourang S, Namdari M. Assessment of coverage error for two common commercial dental shade guides using a spectrophotometric method. *Color Res Appl*. 2022;47:528–536.
36. Ho DK, Ghinea R, Herrera LJ, Angelov N, Paravina RD. Color range and color distribution of healthy human gingiva: A prospective clinical study. *Sci Rep*. 2015;5:1–7.
37. Ren J, Lin H, Huang Q, Zheng G. Determining color difference thresholds in denture base acrylic resin. *J Prosthet Dent*. 2015;114:702–708.
38. Sarmast ND, Angelov N, Ghinea R, Powers JM, Paravina RD. Color compatibility of gingival shade guides and gingiva-colored dental materials with healthy human gingiva. *Int J Periodontics Restorative Dent*. 2018;38:397–403.
39. CIE Technical Report. Colorimetry CIE Publication No. 15.3. Vienna, Austria: Commission Internationale de l'Eclairage (CIE or International Commission on Illumination); 2004.
40. Paravina RD, Ghinea R, Herrera LJ, et al. Color difference thresholds in dentistry. *J Esthet Restor Dent*. 2015;27:S1–S9.
41. Pérez MM, Ghinea R, Herrera LJ, Carrillo F, Ionescu AM, Paravina RD. Color difference thresholds for computer-simulated human Gingiva. *J Esthet Restor Dent*. 2018;30:E24–E30.
42. Gómez-Polo C, Muñoz MP, Luengo MCL, Vicente P, Galindo P, Casado AMM. Comparison of the CIELab and CIEDE2000 color difference formulas. *J Prosthet Dent*. 2016;115:65–70.
43. Gómez-Polo C, Montero J, Gómez-Polo M, Martin Casado A. Comparison of the CIELab and CIEDE 2000 color difference formulas on gingival color space. *J Prosthodont*. 2020;29:401–408.
44. Gómez-Polo C, Montero J, Martín Casado AM. Dental student, dentist, dental assistant, and layperson perception of pink gingival porcelain color. *J Prosthet Dent*. 2022;127:134–140.
45. Tabatabaian F, Khezri AS, Ourang SA, Namdari M. Assessment of coverage error for two common comercial dental shade guides using a spectrophotometric method. *Color Res Appl*. 2022;47:528–536.
46. Armitage P, Berry G, Matthews JNS. *Statistical Methods in Medical Research* Oxford: Blackwell Science; 2002:239–242.
47. Kim HY. Statistical notes for clinical researchers: Post-hoc multiple comparisons. *Restor Dent Endod*. 2015;40:172–176.
48. Naranjo MJ, Gómez-Polo M, Gómez-Polo C, Celemin-Viñuela A. Study of attached gingiva space color according to gender and age in Caucasian population. *J Esthet Restor Dent* 2023.
49. Sailer I, Fehmer V, Ioannidis A, Hämmerle CH, Thoma DS. Threshold value for the perception of color changes of human gingiva. *Int J Periodontics Restor Dent*. 2014;34:757–762.
50. Ruiz-López J, Perez MM, Lucena C, et al. Visual and instrumental coverage error of two dental shade guides: An in vivo study. *Clin Oral Investig*. 2022;26:5961–5968.

Corresponding author:
Dr Cristina Gómez-Polo
Department of Dentistry
School of Medicine
University of Salamanca
s/n Campus Miguel de Unamuno
Salamanca 37007
SPAIN
Email: crisgodent@usal.es.

https://doi.org/10.1016/j.prosdent.2023.09.002