Journal of Dentistry 138 (2023) 104648

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.elsevier.com/locate/jdent

Fifteen ceramic gingival samples: A proposed gingival shade guide

Cristina Gómez-Polo [a,*], Ana María Martín-Casado [b], Javier Montero [a]

[a] Department of Dentistry, School of Medicine, University of Salamanca, Campus Miguel de Unamuno s/n, Salamanca 37007, Spain
[b] Department of Statistics, School of Medicine, University of Salamanca, Spain

ARTICLE INFO

Keywords:
Gingival shade tabs
Ceramic gingival system
Clinical acceptability thresholds
CIELAB coordinates
Chromatic coverage error

ABSTRACT

Objective: (1) To put forward a set of valid pink ceramic samples for subjective gingival colour selection in the Caucasian population, and (2) to assess the quality of the shade matches provided by the selected pink samples.
Methods: The ceramic gingival shade samples (n = 133) were obtained by mixing pairs of basic colours from a single system. In each mixture, the proportions of the colours were altered in 10% increments, following the numerical order used by the manufacturers of the three colour systems under study (Heraceram, Vita VM9 and IPS Style). The CIELAB colour coordinates were recorded using spectrophotometry in three zones of healthy anterior gingiva (n = 360). The sample was randomly divided into two subsamples, each of which contained 180 participants. Subsample 1 was used to select the ceramic gingival samples that provided the best shade matches, using the k-means clustering method. Subsample 2 was used to assess the chromatic validity of the selected gingival samples, according to the coverage error.
Results: To identify the ceramic gingival samples that best represented participants' gingival colour, the minimum colour differences (ΔEab*, ΔE00) between the cluster centroids and the 133 gingival samples were calculated. Fifteen gingival samples were selected: 8 from the Heraceram system, 4 from the VM9 system, and 3 from the IPS Style system. Coverage errors for the 15 gingival samples fell below the gingival clinical acceptability thresholds in the three gingival zones examined.
Conclusions: The 15 ceramic gingival colour samples provide satisfactory coverage of the gingival colour space, with coverage errors below the ΔE00 clinical acceptability threshold of 2.9 units. These pink colour samples have the potential to provide good gingival shade matches in subjective colour selection.
Clinical Significance: Mixing basic ceramic colours is a viable method for generating a series of pink shades that can be used as a physical gingival shade guide. The resulting guide provides valid results (under the acceptability thresholds) for subjective selection gingival colour selection in clinical practice.

1. Introduction

Manufacturers are currently expanding the range of pink shades they offer, in order to meet patients' expectations when it comes to gingival aesthetics. Colour has been shown to be the key variable in determining the attractiveness of a smile [1–4], while a harmonious relationship between teeth and gingiva also plays an important role [2,5–9]. The colour of gingival tissue varies significantly [6,10] in the distinct anatomical regions (papillae, free gingival margin, attached gingiva and mucogingival line) [2,11]. It is also affected by factors such as: the thickness of the epithelium [12], frequency of toothbrushing [2], the degree of keratinisation, pigmentation [13,14], the degree of vascularisation, medication [15], smoking habits [16], age [17], and race [17–21].

Traditionally, narrative description has been used to define gingival shades (from a pale pink colour to a bluish-purple) [13,22], based on visual examination [16,23,24]. While subjective visual comparison is the most common shade selection method in contemporary dentistry [25], the use of electronic devices such as spectrophotometers, spectroradiometers and colorimeters is essential to objectively quantify colours and the variations therein [2,18,26–29].

Successfully emulating the colour of the gingiva adjacent to direct or indirect restorations is a complex challenge [2,30–33], which is further complicated by the lack of benchmark shade guides for the "pink" colour space that are widely used by dental professionals (dental prosthetists and dentists). Alongside their pink restorative materials, manufacturers offer only a limited number of shade tabs with which to perform subjective shade matching. These guides therefore fail to cover the entirety

* Corresponding author.
E-mail address: crisgodent@usal.es (C. Gómez-Polo).

https://doi.org/10.1016/j.jdent.2023.104648
Received 17 July 2023; Received in revised form 29 July 2023; Accepted 31 July 2023
Available online 1 August 2023

of the gingival colour space, limiting their validity for the various target populations and resulting in compromised aesthetic outcomes. Consequently, patients are more likely to consider the final appearance of restorations unsatisfactory when gingival tissue is involved.

The clear colour differences between commercial gingival shade guides and healthy gingiva [6,28,34,35] illustrate the need to use mathematical principles (taking into account the gingival perceptibility and acceptability thresholds) [34] to design a valid gingival guide. Such a guide should have a representative number of gingival shade tabs and cover the natural gingiva colour spectrum, so as to optimise the process of subjective gingival shade matching [31,36].

Several studies [26,29,31,36] have used cluster analysis to select a range of gingival colours (identified by their colour coordinates) that would provide coverage of the gingival colour space for all population groups. These results are limited by the fact that they only provide the colour coordinates, without detailing how to use them to generate physical shade tabs, which limits their utility for procedures involving subjective colour selection through direct visual comparison. Producing a valid physical shade guide for gingiva is an essential step on the path to creating gingival restorations that emulate the colour of adjacent gingiva successfully and make "pink" aesthetic results more predictable. The clinical situations most frequently affected by such interventions are gingival recessions, trauma, iatrogenic extractions, and tumours and/or cysts [1,3,37–40].

Colour differences are quantified in dentistry with reference to the thresholds of perceptibility (PT) and acceptability. The 50:50% PT refers to a colour difference that 50% of observers perceive and the other 50% do not, while the 50:50% AT refers to a colour difference that 50% of observers deem acceptable and the remaining 50% do not. In the gingival colour space, the 50:50% ATs identified in the literature are 4.6 [41], 3.7 [42] and 4.1 units [32] for the Euclidean formula, and 4.0, [41], 2.8 [42] and 2.9 [32] units for the CIEDE2000 formula.

The CIELAB colour space is a Cartesian coordinate system defined by three colorimetric coordinates: L*, a* and b*. The L* coordinate indicates lightness, with values that range between 0 and 100 (vertical axis), while the a* coordinate shows the amount of red/green present (horizontal axis), and the b* coordinate indicates the amount of blue/yellow present (horizontal axis). Two colour-difference formulae are used extensively in dentistry: the Euclidean formula (ΔE_{ab}) and the CIEDE2000 formula (ΔE_{00}). It should be noted that the CIEDE2000 formula correlates more closely with the perception of the gingival colour space by the human eye [43] and is the formula recommended by the CIE [6,44,45], whereas ΔE_{ab} is the most frequently used formula, facilitating comparison with previous results [6].

The null hypothesis of this study was that the pink ceramic gingival samples would not provide coverage of the gingival colour space and perform satisfactorily in shade matching (under the acceptability threshold) in a Caucasian population. The objectives of this study were: 1 – to select valid gingival samples that represent the gingival colour of the Caucasian population, by producing ceramic mixtures using three gingival colour systems; 2 – to assess the quality of the shade matches achieved with these physical ceramic gingival shade tabs.

2. Materials and methods

2.1. Ceramic gingival samples

A set of 133 ceramic gingival colour samples was used in this study (identified as Heraeus H1-H51, Vita V1-V41, and Ivoclar I1-I41). These were obtained by mixing the basic shades from the following three ceramic gingival colour systems: Heraceram – Heraeus-Kulzer (6 basic gingival colours); Vita VM9 – Vita-Zahnfabrik (5 basic gingival colours); IPS Style – Ivoclar (5 basic gingival colours). To create the ceramic gingival shade samples, pairs of basic colours from a single system were mixed, changing the proportion of the colours in each consecutive mixture by 10%, and following the numerical order used by the manufacturers. Three colour measurements were taken for each pink ceramic sample, using the Spectroshade Micro (MHT Optic Research AG, Niederhasli, Switzerland) spectrophotometer against a neutral grey background lit by fluorescent-tube ceiling lights (Phillips TLD 95/65). These were used to obtain the mean L*, a* and b* coordinates for each sample. The CIELAB colour-coordinate ranges were as follows for each of the three ceramic colour systems expanded with the aforementioned mixtures: Heraceram (n = 51) – L*: 36.9–67.3; a*: 13.6–32.9, b*:5.3–20.8; Vita VM9 (n = 41) – L*: 37.8–62.8; a*: 11.8–30.4, b*:8.1–20.9; IPS Style (n = 41) – L*: 46.2–63.0; a*: 13.2–23.3, b*:4.6–25.7.

2.2. The participants' gingival colour coordinates

The participants in this study were 360 Caucasian subjects with healthy gingival tissue around the maxillary central incisor (187 men and 173 women), aged between 18 and 92 years. The exclusion criteria were visible signs of gingival inflammation, presence of plaque, missing teeth in the maxillary anterior region, melanin pigmentation, and having received dental whitening treatment. All participants signed an informed consent form, and the study was approved by the Institutional Bioethics Committee. For each participant, the L*, a* and b* colour coordinates were recorded in three attached gingival zones (the mucogingival line, middle zone and free gingival margin) [46] using the spectrophotometer (SpectroShade Micro, MHT Optic Research AG, Niederhasli, Switzerland) and repeating the measurements three times. These colour measurements were conducted in standardised conditions: by the same operator, using the same dental cabinet, and with lighting from daylight-coloured fluorescent tubes (Phillips TLD 95/65). For the statistical calculations, the mean coordinates were used. The minimum and maximum CIELAB colour coordinates were as follows for each of the three zones examined (n = 360). Mucogingival line – L*: 28.3–65.4; a*: 11.2–36.6, b*: 6.9–25.2; middle zone – L*: 31.5–64.2; a*: 12.1–37.2, b*: 8.6–24.9; free gingival margin – L*: 30.1–63.5; a*: 11.1–36.9, b*: 7.4–24.8.

2.3. Selection of the most representative ceramic gingival samples

The total sample of participants was randomly divided into two subsamples, each including 180 subjects. Subsample 1 was used to select the ceramic samples that mostly closely matched the gingival shades of the subsample, according to the clinical acceptability thresholds. Subsample 2 was used to assess the chromatic validity of the ceramic gingival samples selected in the first stage.

Selection of the ceramic gingival samples that provided the best shade matches was conducted by applying the k-means algorithm to the 180 participants in subsample 2 (k-means clustering). This optimisation algorithm is a non-hierarchical cluster analysis method, in which a partition is iteratively updated as each object is reallocated to the group with the nearest mean, followed by recalculation of the group means [47]. The selection process included four stages, as follows.

(1) *The k-means algorithm was applied:* using the CIELAB colour coordinates recorded for the 180 subjects in each gingival zone, the algorithm was applied for different numbers of clusters (k = 2, 3, 4, etc.).
(2) *The final groups were chosen*. In each attached gingival zone, a final group was chosen: that with the minimum number of clusters fulfilling the condition that each cluster contains 5 or more subjects (approximately 2.5% of the total number of participants in subsample 1).
(3) *The most representative ceramic gingival samples were identified in each cluster, in each of the three attached gingival zones*. To do so, the colour difference was calculated (using the Euclidean and CIEDE2000 formulae) between each centroid (the colour that is representative of the cluster, at the centre of the cluster's data

points) and the 133 porcelain gingival samples. The ceramic gingival colour sample with the smallest colour difference (or the two samples, when the two colour difference formulae did not identify the same tab) was then identified.

(4) *The selected ceramic gingival samples were assembled in a proposed physical gingival shade guide*: the gingival guide described in this article was created by bringing together the representative ceramic gingival samples from the clusters in each gingival zone and organising the samples in ascending order of lightness (L* coordinate).

2.4. Assessment of how the selected gingival samples perform in shade matching

Subsample 2 was used to assess the chromatic performance of the selected ceramic gingival samples in each gingival zone, based on the following indicators: (1) the coverage error [48], or the mean of the minimum colour differences between the gingiva of the members of subsample 2 and the best-performing ceramic colour samples selected earlier [28,48,49]; and (2) the quality of the shade match achieved – excellent, acceptable, moderately unacceptable, clearly unacceptable or extremely unacceptable [50].

For each participant in subsample 2 ($n = 180$), the ceramic gingival sample was selected for which the colour difference with respect to the gingival zone in question was smallest (ΔE_{min}). The average of the minimum colour differences for the 180 participants was then calculated (CE):

$$CE = \frac{\sum \Delta E_{min}}{n} = \frac{\sum_{i=1}^{n} \min_{j} \Delta E_{ij}}{n}$$

where ΔE_{ij} is the difference between the gingival colour recorded for the participant, i ($i = 1, \ldots, n$), and that recorded for the shade tab (j).

The coverage error was calculated in each of the three attached gingival zones in which the colour coordinates were measured, using the Euclidean (ΔE_{ab}) and CIEDE2000 (1:1:1) (ΔE_{00}) formulae to determine the colour differences.

The quality of the shade match achieved for each participant was established in the following way [50]:

- If the colour difference between the participant's gingiva and the ceramic gingival sample selected (that providing the best shade match) was lower than or equal to the perceptibility threshold ($\Delta E_{min} \leq PT$), the shade match for that participant was considered excellent.
- If the colour difference between the gingiva and the best-performing gingival sample was between the perceptibility threshold and the acceptability threshold ($PT < \Delta E_{min} \leq AT$), the shade match was considered acceptable.
- If the colour difference between the gingiva and the best-performing shade tab was between the acceptability threshold and twice that value ($AT < \Delta E_{min} \leq 2 \times AT$), the shade match was considered moderately unacceptable.
- If the colour difference between the gingiva and the best-performing shade tab was between two and three times the acceptability threshold ($2 \times AT < \Delta E_{min} \leq 3 \times AT$), the shade match was considered clearly unacceptable.
- If the colour difference between the gingiva and the best-performing shade tab was more than three times the acceptability threshold ($\Delta E_{min} > 3 \times AT$), the shade match was considered extremely unacceptable.

This classification of participants according to shade-match quality was performed with reference to the various perceptibility and acceptability thresholds found in the relevant literature [32,41,42,51].

3. Results

The number of clusters varied according to the zone of attached gingiva examined in subsample 1 ($n = 180$). At the mucogingival line, the chosen solution consisted of 4 clusters, while the solutions in the middle zone and at the free gingival margin consisted of 7 and 6 clusters, respectively (Table 1 and Fig. 1).

Fig. 1 shows the colour coordinates of the 133 ceramic gingival samples and of the 180 participants in subsample, measured in the middle zone of the attached gingiva.

The minimum colour differences between the centroids of the clusters and the 133 ceramic gingival samples are shown in Table 2, which also shows the gingival colour samples that most closely matched the centroids (one, when the closest-matching ceramic gingival sample identified was the same for both colour difference formulae; two, when the two formulae identified different samples).

The 15 pink ceramic samples that appear at least once in Table 2 were selected: H24, H26, H35, H40, H41, H42, H45 and H49 from the expanded Heraceram system; V29, V30, V32 and V34 from the expanded Vita VM9 system; and I26, I27 and I33 from the expanded IPS Style system. The ceramic gingival samples in Table 2, which were selected for providing the closest shade match with the centroids of the clusters (Fig. 2), appear in ascending order of lightness in Table 3 and Fig. 3.

Table 4 shows the coverage errors obtained in subsample-2 of 180 participants. This subsample was used to assess the performance of the 15 ceramic gingival samples selected through the statistical analysis performed upon subsample 1 ($n = 180$), as detailed above.

As Table 4 shows, all the coverage errors fall below the 50:50% acceptability thresholds found in the literature. This is true of the coverage errors for both genders and all age groups. Further, the coverage errors are similar for women and men, in all age groups, and in all three attached gingival zones, whether calculated with the Euclidean or CIEDE2000 formula.

In Figs. 4–6, the 180 participants in subsample 2 are classified according to the quality of shade match achieved, in the three attached gingival zones examined, using the CIEDE2000 formula to calculate the colour differences. As the figures show, none of the 180 participants in subsample 2 received an extremely unacceptable shade match in any of the attached gingival zones, according to any of the gingival thresholds of clinical acceptability considered in this study.

When the colour differences were calculated with the Euclidean formula, the percentages of participants whose shade-match at the

Table 1

Centroids of the clusters, and the number of participants grouped together in each cluster, according to the zone of attached gingiva (subsample 1, $n = 180$).

		L*	a*	b*	# participants
Mucogingival line					
	Cluster 1	37.6	33.4	16.7	52
	Cluster 2	42.8	26.8	13.9	5
	Cluster 3	50.6	23.7	14.5	69
	Cluster 4	55.9	20.0	15.8	54
Middle zone					
	Cluster 1	39.8	33.7	16.6	7
	Cluster 2	42.1	25.3	12.4	25
	Cluster 3	48.2	28.5	14.9	39
	Cluster 4	50.2	21.3	13.2	32
	Cluster 5	50.5	22.2	18.7	17
	Cluster 6	54.7	23.9	14.9	40
	Cluster 7	59.3	19.8	17.2	20
Free gingival margin					
	Cluster 1	37.7	34.7	18.2	36
	Cluster 2	38.2	21.4	10.4	40
	Cluster 3	44.4	28.0	14.0	58
	Cluster 4	49.4	20.6	14.3	34
	Cluster 5	52.2	25.6	14.7	5
	Cluster 6	57.3	20.0	15.4	7

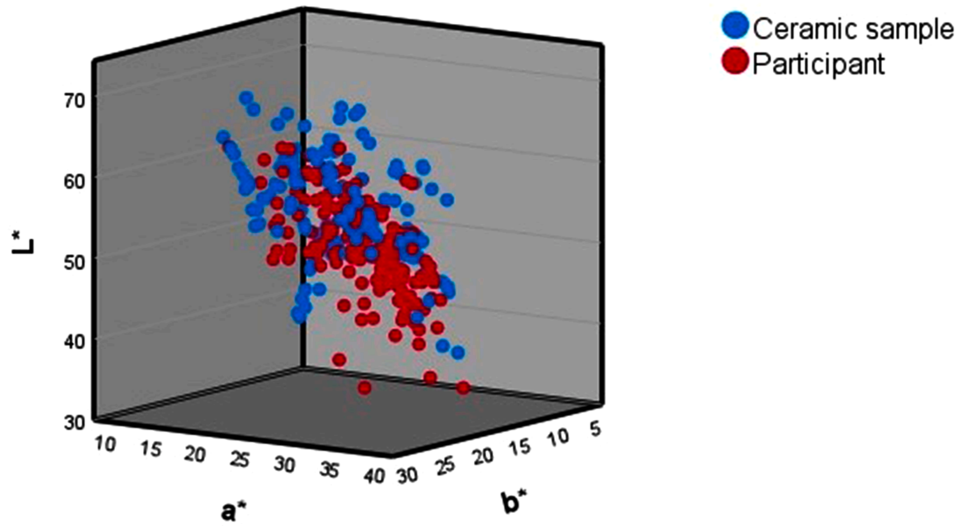

Fig. 1. The L*, a* and b* coordinates of the 133 ceramic gingival samples used in this study, and of the 180 participants in subsample 1, measured in the middle zone of the attached gingiva.

Table 2
Closest-matching ceramic gingival samples, and colour differences between these samples and the centroids, according to the zone of attached gingiva (subsample 1, $n = 180$).

		Ceramic gingival sample	ΔE_{ab}	ΔE_{00}
Mucogingival line				
	Cluster 1	H45	3.14	1.82
	Cluster 2	H35	4.16	2.18
	Cluster 3	H26, V30	2.48	1.91
	Cluster 4	I26	1.91	1.63
Middle zone				
	Cluster 1	H40, H45	3.35	2.04
	Cluster 2	H49, H35	5.92	2.91
	Cluster 3	H41, H42	1.56	1.14
	Cluster 4	V32	2.39	1.85
	Cluster 5	I33	2.51	1.86
	Cluster 6	V29	2.13	1.76
	Cluster 7	I27, H24	2.19	1.63
Free gingival margin				
	Cluster 1	H45	4.98	2.56
	Cluster 2	V34, H45	6.49	5.18
	Cluster 3	H35	2.97	1.62
	Cluster 4	V32	1.44	0.82
	Cluster 5	H26	0.80	0.54
	Cluster 6	I26	1.68	1.36

mucogingival line was classified as excellent or acceptable were 81.1%, 65.0% and 75.0%, using the thresholds described by Ren et al., Pérez et al. and Gómez-Polo et al., respectively [41–43]. In the middle zone, the percentages were 82.2%, 65.5% and 71.7% for the three thresholds, and at the free gingival margin, they were 78.3%, 62.3% and 72.2%. When the colour differences were calculated with the CIEDE2000 formula, the percentages of participants receiving an excellent or acceptable shade match at the mucogingival line were 92.2%, 73.9% and 76.7%, using the three thresholds cited above. In the middle zone, the percentages were 95.0%, 75.6% and 77.7% for the three thresholds, and at the free gingival margin, they were 78.3%, 62.3% and 72.2%. As shown in Figs. 4–6, the poorest shade matches were achieved at the free gingival margin.

4. DISCUSSION

The null hypothesis should be rejected, since ceramic gingival samples have been identified that satisfactorily represent the gingival colour space in the study population. This population ($n = 360$) is similar in size to those used in prior publications [2,26,52]. The authors of the aforementioned studies [2,26,52] also used a spectrophotometer to record colour coordinates, given the device's demonstrated reliability *in vivo* and when used with samples of pink material *in vitro* [2,30,53–57]. It is well known that spectrophotometers are subject to the limitations of "edge loss" [58], whereby some colour information is lost when the incident light falls on translucent surfaces. Spectrophotometers are considered the most precise electronic devices for recording colour coordinates in dentistry [59,60]. Due to the design of their probe tips and/or cameras, those currently on the market do not enable measurements to be taken in the posterior region. Consequently, this and other studies using spectrophotometers measure the colour of the gingiva adjacent to the incisors. Given the diversity of gingival colour, as described in previous research, the results have been presented for three distinct anatomical areas [2,16] and according to gender [2,26,29,52]. Research on how age influences the colour of keratinised gingiva is not conclusive. While several publications found no statistically significant differences between age groups [2,18,26,29], other recent results have suggested that the attached gingiva may develop a bluish colour as subjects age [52].

It should be noted that we cannot rule out the possibility of chromatic differences existing between distinct batches of gingival ceramics or slight errors having been made in the proportions used in the mixtures, both of which would introduce errors into the results presented. Other limitations of the research include the omission of gingival papillae, and the fact that all 360 participants in the sample were Caucasian, which prevents the extrapolation of these findings to other racial populations [18]. Future studies should address these omissions, in order to interrogate whether the 15 ceramic gingival samples selected are representative when used in other anatomical regions and racial groups. Further research is also needed to explore other ceramic gingival systems, other restorative materials (including those produced by different manufacturers) and mixtures containing different proportions of the various shades, in order to consolidate and expand the results presented in this paper. There are other methods for widening the gingival colour range that were beyond the scope of this study, such as the application of dyes and stains [34] to alter the appearance of restorations, but the results of these techniques are more difficult to quantify.

The chromatic criteria used by manufacturers to design the basic colours in their restorative systems are unknown, but they have proved

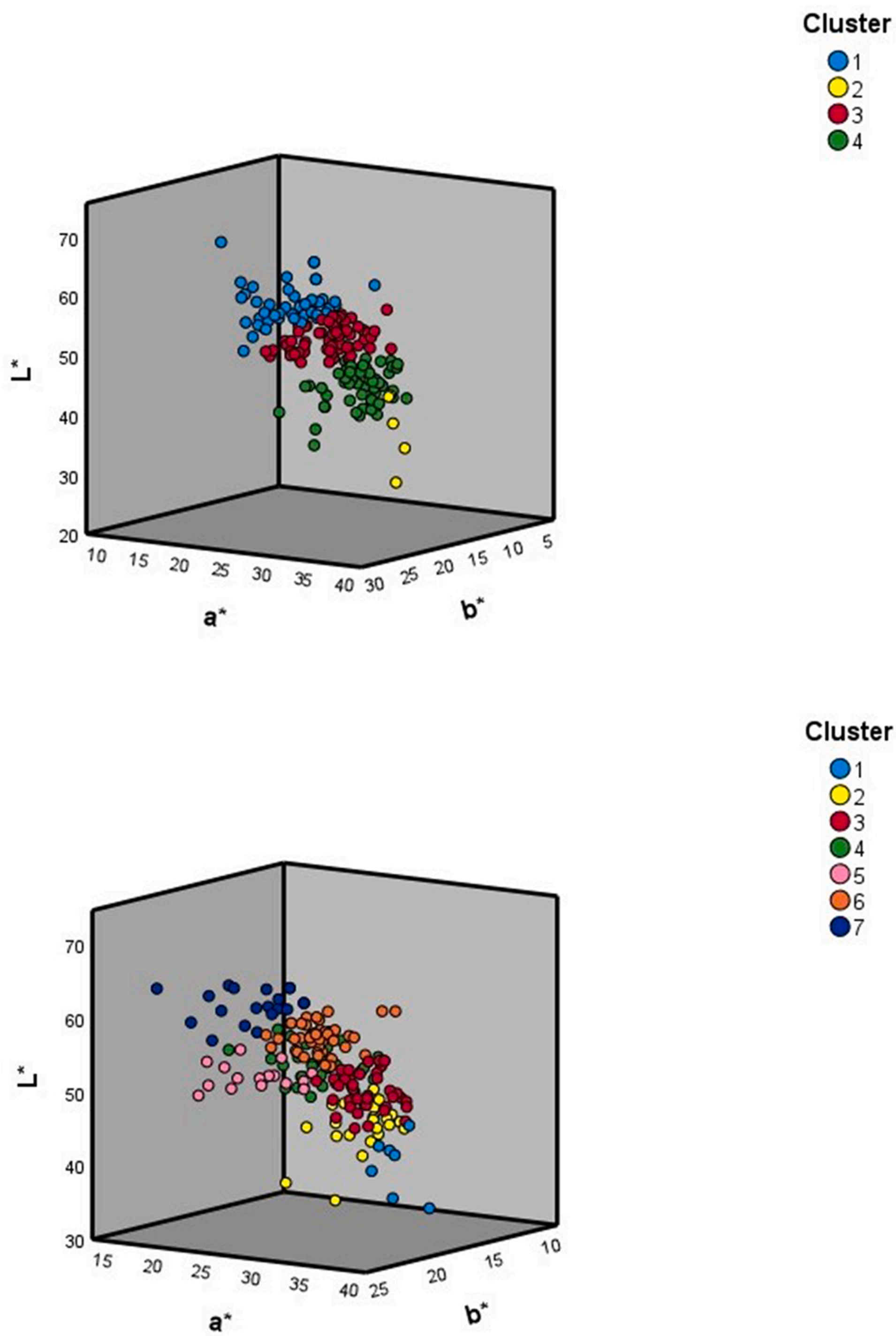

Fig. 2. Number of clusters according to the attached gingival zone examined in subsample 1 (n = 180). Mucogingival line – 4 clusters, middle zone – 7 clusters, and free gingival margin – 6 clusters.

insufficient to guarantee satisfactory aesthetic results. Studies on the chromatic compatibility of the available gingival shade guides – Eclipse (Dentsply), Gumy (Shofu), IPS e.max (Ivoclar Vivadent), GC Acrylic (GRADIA Gum Shades®; GC America, Inc., Alsip, IL, USA), IvoCap® (Ivoclar Vivadent, Inc., Laguna, Philippines), Lucitone 199® (Dentslpy International, Hong Kong, China), Easy-Flow® (Henry Schein, Hong Kong, China), Candulor® (Ivoclar Vivadent, Inc., Laguna, Philippines), Heraceram (Kulzer), IPS Gingival and IPS d.sign (Ivoclar, AG) – agree [6,28,34,35] that the coverage error between the shade tabs and the gingival colour recorded for the various populations is not acceptable (exceeding the chromatic acceptability threshold), and that these shade guides do not represent natural gingival colour (ΔE_{ab}CE >8.0). Sarmast et al. [6] identified an exception in 2018, finding that the Vita VM9 gingival guide performed satisfactorily in shade matching, with colour differences below the acceptability threshold. In 2009, Bayindir et al. [28] observed that the CE decreased (ΔE_{ab}CE 7.9) when two gingival shade guides were combined: the 4 gingival shade tabs of the Lucitone 199 guide (Denstply, Sirona) having been used together with the 10

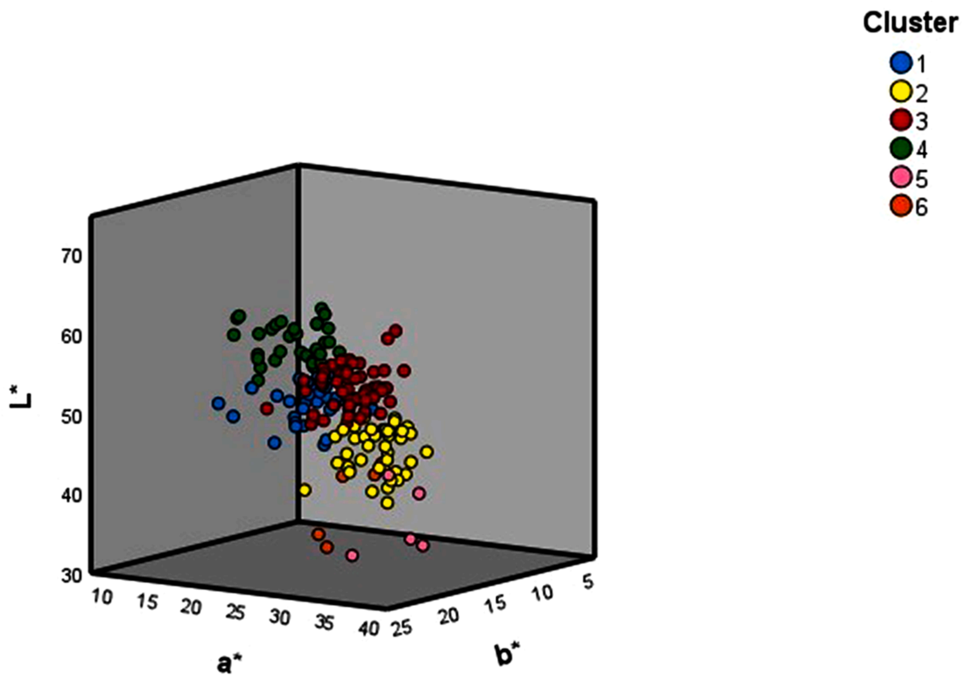

Fig. 2. (*continued*).

Table 3
Mean colour coordinates (SD) of the 15 ceramic gingival samples included in the proposed physical gingival guide.

Samples	Ceramic Gingival System	Composition	L*	a*	b*
1	HERACERAM	60G7+40G8	38.4 (0.1)	32.5 (0.2)	13.8 (0.1)
2	HERACERAM	10G6+90G7	42.9 (0.1)	32.9 (0.6)	17.7 (0.4)
3	VITA VM9	70G4+30G5	42.9 (0.1)	17.2 (0.2)	12.0 (0.2)
4	HERACERAM	60G6+40G7	43.7 (0.1)	30.9 (0.6)	13.7 (0.3)
5	HERACERAM	20G7+80G8	44.1 (0.1)	30.7 (0.2)	10.9 (0.2)
6	HERACERAM	90G7+10G8	49.1 (0.2)	29.8 (0.5)	14.6 (0.3)
7	VITA VM9	90G4+10G5	49.2 (0.4)	19.2 (0.5)	13.9 (0.3)
8	HERACERAM	G7	49.5 (0.3)	29.4 (0.4)	15.2 (0.2)
9	VITA VM9	10G3+90G4	49.5 (0.1)	24.3 (0.4)	17.0 (0.3)
10	IPS STYLE	80G4+20G5	52.1 (0.1)	20.5 (0.1)	17.8 (0.1)
11	HERACERAM	50G5+50G6	52.7 (0.2)	25.1 (0.2)	14.3 (0.1)
12	VITA VM9	20G3+80G4	53.4 (0.2)	23.4 (0.2)	16.5 (0.2)
13	IPS STYLE	50G3+50G4	57.2 (0.1)	18.8 (0.1)	16.6 (0.1)
14	IPS STYLE	40G3+60G4	57.4 (0.1)	18.8 (0.1)	17.0 (0.1)
15	HERACERAM	70G5+30G6	60.8 (0.3)	19.4 (0.4)	15.6 (0.4)

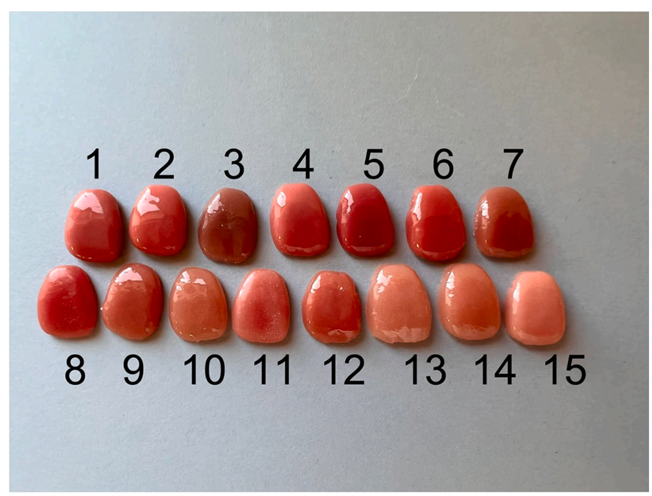

Fig. 3. The 15 ceramic gingival samples in the gingival shade guide proposed in this study.

shade tabs from the IPS Gingival guide (Ivoclar, AG). This illustrated the need to explore how shade-matching performance is affected when using several gingival colour systems. The present study responds to that need by investigating the extent to which expanding existing colour systems by producing porcelain mixtures can optimise the chromatic solutions offered. Given that 133 physical gingival samples would have been a much greater number than that used in previous studies [6,28,34,35] and impracticable for direct subjective visual comparisons, 15 tabs were selected in this study. This is a more manageable number for clinicians and analogous to the 16 dental shade tabs in the Vita Classical guide (which is considered the gold standard for dental shade guides) while providing a range that is compatible with the gingival colour space recorded *in vivo*. The 15 gingival samples selected with subsample 1 produced a CE, when assessed with subsample 2, which fell below the clinical acceptability threshold for gingiva. They therefore met the objectives of compatibility with the gingival colour space in all the age groups, both genders and the three gingival zones ($\Delta E_{ab}CE < 3.72$). These results suggest that the guide may perform better in shade matching than those currently on the market. The quality of shade matches was excellent or acceptable for around 75% of participants in the middle zone and at the mucogingival line, while lower percentages were achieved at the free gingival margin. It has not been possible to

Table 4
Coverage errors (SD), according to the zone of attached gingiva: for the total subsample (subsample 2, $n = 180$), by gender, and by age group.

		ΔE_{ab}	ΔE_{00}
Mucogingival line			
Total subsample (n = 180)		**3.49 (1.67)**	**2.35 (1.10)**
By gender			
	Women ($n = 90$)	3.34 (1.66)	2.25 (1.07)
	Men ($n = 90$)	3.63 (1.68)	2.44 (1.12)
By age group			
	14–30 years	2.97 (1.29)	1.99 (0.86)
	31–45 years	3.31 (1.44)	2.19 (0.87)
	46–60 years	3.67 (1.90)	2.60 (1.26)
	Over 60 years	3.68 (1.80)	2.53 (1.19)
Middle zone			
Total subsample (n = 180)		**3.34 (1.53)**	**2.26 (0.97)**
By gender			
	Women ($n = 90$)	3.47 (1.66)	2.34 (1.04)
	Men ($n = 90$)	3.22 (1.38)	2.18 (0.89)
By age group			
	14–30 years	3.17 (1.17)	2.20 (0.92)
	31–45 years	3.29 (1.88)	2.22 (1.06)
	46–60 years	3.68 (1.57)	2.45 (1.00)
	Over 60 years	3.17 (1.40)	2.14 (0.87)
Free gingival margin			
Total subsample (n = 180)		**3.53 (1.62)**	**2.37 (1.07)**
By gender			
	Women ($n = 90$)	3.52 (1.65)	2.34 (1.09)
	Men ($n = 90$)	3.53 (1.59)	2.40 (1.05)
By age group			
	14–30 years	3.18 (1.71)	2.35 (1.24)
	31–45 years	3.56 (1.44)	2.35 (0.98)
	46–60 years	3.61 (1.49)	2.33 (1.00)
	Over 60 years	3.72 (1.81)	2.45 (1.09)

make any direct comparisons with other authors' results given the lack of similar studies, to date, focused on the gingiva.

Another common strategy for obtaining valid gingival shades that are able to cover the gingival colour space for the various populations studied [2,18,26] is to mathematically calculate their colour coordinates using cluster methodology (the colour coordinates of the centroids identify the gingival shade obtained), taking into account the clinical acceptability thresholds [26,29,31,36]. The findings of such studies have varied: Huang et al. [36] described 10 gingival colours (centroids) – the ΔE_{ab}CE was not provided, but it exceeded the clinical acceptability thresholds; Gómez Polo et al. [2] identified 8 (ΔE_{ab}CE 3.5); Ghinea et al. [31] obtained 6 (ΔE_{ab}CE 2.9), and Ito et al. [29] identified 3 (ΔE_{ab} CE 4.6). As this illustrates, mathematically calculated colours have lower CEs than the gingival shade tabs on the market, but they have the disadvantage of providing no physical format for use in subjective visual comparisons. The differences in the numbers of clusters described in the aforementioned studies may stem from: the distinct colour-coordinate ranges in the various racial populations studied, the different digital devices used for colour measurement, or the distinct cluster-calculation methods used. The variation in the colour-coordinate ranges of the gingival shades obtained in these studies is as follows: (L min=35.6, L max=53.9; a min= 9.23, a max= 19.46; b min= 6.81, b max= 20.17) Huang [36], (L min=42.9, L max=56.0; a min= 19.9, a max= 34.1; b min= 10.9, b max= 19.1) Gómez Polo [2], (L min=36.1, L max=61.4; a min= 21.0, a max= 27.7; b min= 16.0, b max= 18.3) Ito [29], and (L min= 43.7, L max= 57.4; a min= 20.4, a max= 25.3; b min= 13.8 b max= 15.6) Guinea [31]. The 15 colour samples described in the present research fall within a similar range (L min= 38.3, L max= 60.8; a min= 17.7, a max= 32.9; b min= 13.8 b max= 17.7). This study's significant improvement upon the aforementioned research is its description of the process for creating physical gingival shades. These 15 ceramic gingival samples can be used to make direct visual comparisons, thereby enabling clinicians to conduct subjective colour selection as part of their routine practice. To date, no publications have focused on the development of a gingival shade guide using physical ceramic samples whose performance is validated with a separate population sample. The methods followed by manufacturers in designing the colours of their rehabilitation-reconstruction materials for gingival tissue are unknown, but there is evidently significant progress to be made in this area, given their failure to provide satisfactory shade matches. It follows that there is no gingival colour system that is genuinely useful by itself, meaning that dental laboratories must draw on several colour systems if they are to provide high-quality colour selection and restorations that reproduce gingival colour with convincing, aesthetically pleasing results.

These 15 ceramic gingival samples have been designed with real clinical contexts in mind, including their shortfalls in selection, communication, reproduction and characterisation of gingival colour. The results could help the industry generate a "gold standard" for gingival shade guides in the future. In addition to testing the 15 ceramic shade tabs in larger samples, different anatomical regions and different racial populations, the option of incorporating new colour samples is worth considering, to ensure that the guide is as chromatically representative as possible. This type of study can help the commercial sector better address the needs and circumstances of clinical settings. Being able to manufacture a suitable number of gingival samples that perform satisfactorily in shade matching is vital if we are to communicate about subjective gingival colour selection in a more rigorous, standardised manner. One of this study's primary contributions is that it provides clinicians with a method to obtain ceramic gingival samples in physical form, which can then be kept on hand in dental cabinets for use in direct comparisons between the colour of the "target" gingiva and the samples.

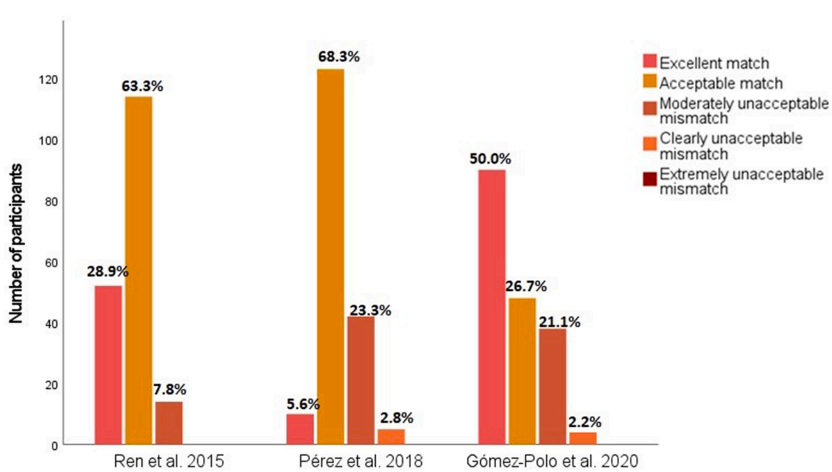

Fig. 4. Classification of the participants in subsample 2 according to match/mismatch category at the mucogingival line of the attached gingiva.

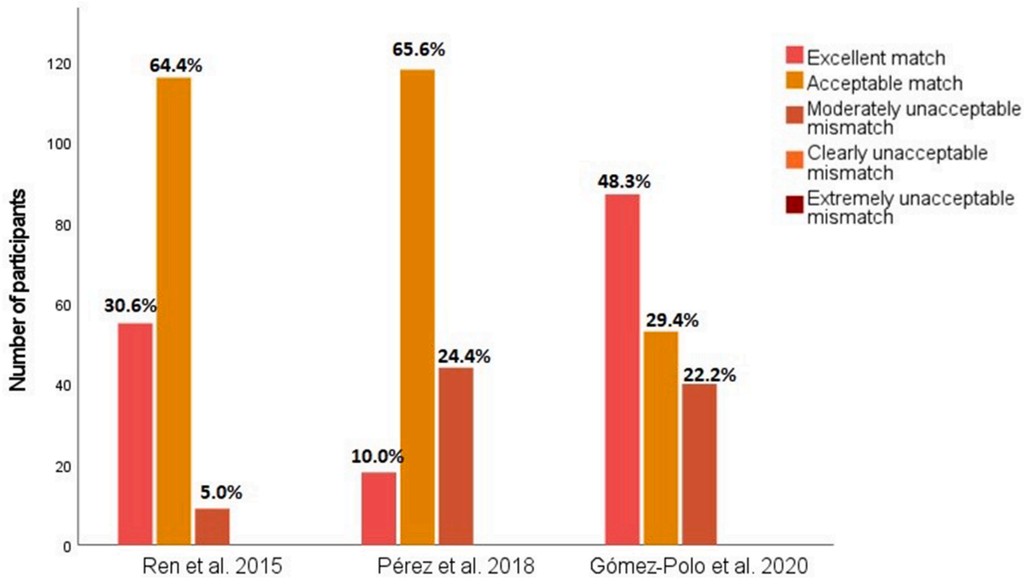

Fig. 5. Classification of the participants in subsample 2 according to match/mismatch category in the middle zone of the attached gingiva.

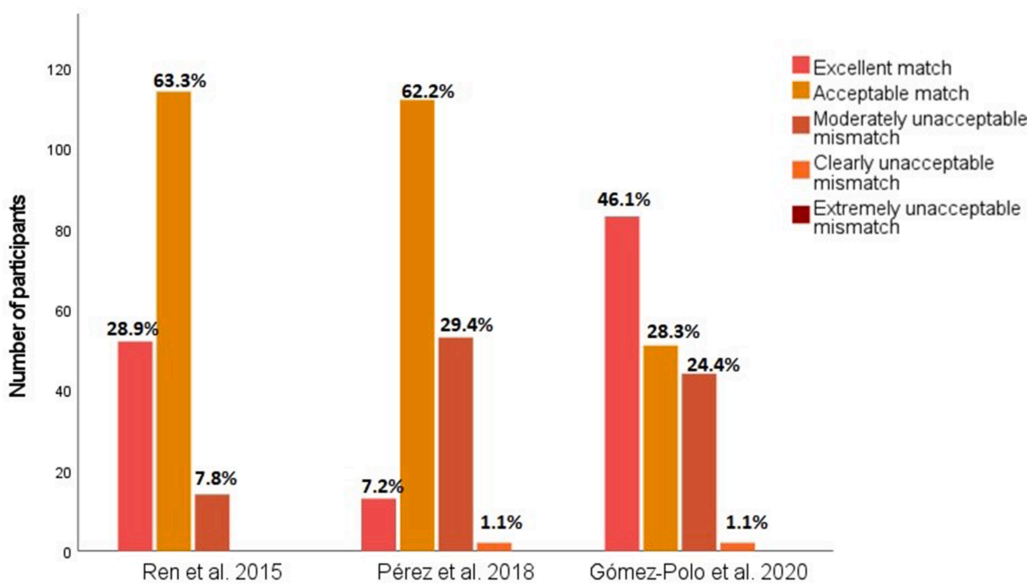

Fig. 6. Classification of the participants in subsample 2 according to match/mismatch category at the free gingival margin of the attached gingiva.

The highly satisfactory results achieved for coverage error are another strength, enabling professionals to use the samples with confidence in the Caucasian population.

5. Conclusions

Within the limitations of this study, we can conclude that:

(1) Fifteen physical ceramic samples were selected with the following colour-coordinate ranges: L* min= 38.3- max= 60.8; a* min= 17.7- max= 32.9; b* min= 13.8 - max= 17.7. The coverage errors in the three zones of attached gingiva were below the acceptability thresholds used in this study.
(2) The chromatic performance of the 15 ceramic samples was satisfactory in all age groups, all zones of attached gingiva, and both genders, acceptable or excellent shade matches having been achieved for over 70% of participants.

Author statement

CGP and JM: Idea, conceptualization, protocol development, results interpretation, and contributed to the manuscript revision. -CGP, AMMC and JM: Contributed to the protocol development, data analysis, results interpretation, and manuscript writing. -CGP: Data collection and measurements and contributed to the manuscript revision

Declaration of Competing Interest

The authors have no conflict of interest

Aknowledgements

The authors would like to thank all participants for their time and consideration. The authors thank to the research group named Avances en Salud Oral of Department of Surgery at the University of Salamanca for the institutional support provided for this research project.

References

[1] A.H. Tjan, G.D. Miller, J.G. The, Some esthetic factors in a smile, J. Prosthet. Dent. 51 (1984) 24–28, https://doi.org/10.1016/s0022-3913(84)80097-9.
[2] C. Gómez-Polo, J. Montero, M. Gómez-Polo, A.M. Martín Casado, Clinical study on natural gingival color, Odontology 107 (2019) 80–89, https://doi.org/10.1007/s10266-018-0365-2.
[3] A. Alani, A. Maglad, F. Nohl, The prosthetic management of gingival aesthetics, Br. Dent. J. 210 (2011) 63–69, https://doi.org/10.1038/sj.bdj.2011.2.
[4] N. Capa, An alternative treatment approach to gingival recession: gingiva-colored partial porcelain veneers: a clinical report, J. Prosthet. Dent. 98 (2007) 82–84, https://doi.org/10.1016/S0022-3913(07)60040-7.
[5] P. Papaspyridakos, S. Amin, K. El-Rafie, H.P. Weber, Technique to match gingival shade when using pink ceramics for anterior fixed implant prostheses, J. Prosthodont. 27 (2018) 311–313.
[6] N.D. Sarmast, N. Angelov, R. Ghinea, J.M. Powers, R.D. Paravina, Color compatibility of gingival shade guides and gingiva-colored dental materials with healthy human gingiva, Int. J. Periodont. Restor. Dent. 38 (2018) 397–403, https://doi.org/10.11607/prd.3430.
[7] P. Van der Geld, P. Oosterveld, G. Van Heck, A.M. Kuijpers-Jagtman, Smile attractiveness. Self-perception and influence on personality, Angle Orthod. 77 (2007) 759–765.
[8] S. Schnitzer, J.C. Türp, G. Heydecke, Color distribution and visual color assessment of human gingiva and mucosa: a systematic review of the literature, Int. J. Prosthodont. 17 (2004) 327–332.
[9] U.C. Belser, B. Schmid, F. Higginbottom, D. Buser, Outcome analysis of implant restorations located in the anterior maxilla: a review of the recent literature, Int. J. Oral Maxillofac. Implants 19 (2004) s30–s42.
[10] N. Valente, I. Sailer, V. Fehmer, D. Thoma, Color differences between pink veneering ceramics and the human gingiva, Int. J. Periodont. Restor. Dent. 38 (2018) s59–s65, https://doi.org/10.11607/prd.3526.
[11] N.P. Lang, J. Lindhe, Clinical Periodontology and Implant Dentistry, Ed 6, Wiley-Blackwell, Chichester, UK, 2015.
[12] N. Claffey, D. Shanley, Relationship of gingival thickness and bleeding of probing attachment in shallow sites following nonsurgical periodontal therapy, J. Clin. Periodontol. 13 (1986) 654–657, https://doi.org/10.1111/j.1600-051x.1986.tb00861.x.
[13] C.O. Dummett, Oral pigmentation, J. Periodontol. 31 (1960) 356–360.
[14] B.C. Longo, T.T.C. Rocha, G.C. Santin, D.N. Tatakis, C.O. Silva, Gingival pigmentation: concurrent assessment of distribution, intensity, and extent in a black population, J. Esthet. Restor. Dent. 34 (2022) 897–906, https://doi.org/10.1111/jerd.12846.
[15] P. Holmstrup, J. Plemons, J. Meyle, Non-plaque-induced gingival diseases, J. Clin. Periodontol. 45 (2018) S28–S43, https://doi.org/10.1111/jcpe.12938.
[16] G. Heydecke, S. Schnitzer, J.C. Turp, The color of human gingiva and mucosa: visual measurement and description of distribution, Clin. Oral Investig. 9 (2005) 257–265.
[17] P. Janiani, P.R. Bhat, V.A. Trasad, A.B. Acharya, S.L. Thakur, Evaluation of the intensity of gingival melanin pigmentation at different age groups in the Indian population: an observational study, J. Indian Soc. Pedod. Prev. Dent. 36 (2018) 329–333, https://doi.org/10.4103/JISPPD.JISPPD_192_17.
[18] D.K. Ho, R. Ghinea, L.J. Herrera, N. Angelov, R.D. Paravina, Color range and color distribution of healthy human gingiva: a prospective clinical study, Sci. Rep. 5 (2015) 18498, https://doi.org/10.1038/srep18498.
[19] A. Masilana, R.A.G. Khammissa, J. Lemmer, L. Feller, Physiological oral melanin pigmentation in a south African sample: a clinical study, J. Investig. Clin. Dent. 8 (2017) 1–6, https://doi.org/10.1111/jicd.12258.
[20] D.O. Oluwole, Gingival tissue color related with facial skin and acrylic resin denture base color in a nigerian population, Afr. J. Biomed. Res. 13 (2010) 107–111.
[21] D. Ponnayan, V. Jegadeesan, G. Perumal, A. Anusha, Correlating skin color with gingiva pigmentation patterns in South Indians- a cross sectional study, Oral Health Dent. Manag. 13 (2014) 132–136.
[22] C.O. Dummett, Oral pigmentation: physiologic and pathologic, N. Y. State Dent. J. 25 (1959) 407–412.
[23] J.M. Powers, J.A. Capp, A. Koran, Color of gingival tissues of blacks and whites, J. Dent. Res. 56 (1977) 112–116, https://doi.org/10.1177/00220345770560020301.
[24] D.O. Dummett, J.S. Sakumura, G. Barens, The relationship of facial skin complexion to oral mucosa pigmentation and tooth color, J. Prosthet. Dent. 43 (1980) 392–396, https://doi.org/10.1016/0022-3913(80)90207-3.
[25] J.C. Ragain, W.M. Johnston, Color acceptance of direct dental restorative materials by human observers, Color Res. Appl. 25 (2000) 278–285.
[26] J.W. Huang, W.C. Chen, T.K. Huang, P.S. Fu, P.L. Lai, C.F. Tsai, C.C. Hung, Using a spectrophotometric study of human gingival colour distribution to develop a shade guide, J. Dent. 39 (2011) e11–e16, https://doi.org/10.1016/j.jdent.2011.10.001.
[27] H.K. Hyun, S. Kim, C. Lee, T.J. Shin, Y.J. Kim, Colorimetric distribution of human attached gingiva and alveolar mucosa, J. Prosthet. Dent. 117 (2017) 294–302, https://doi.org/10.1016/j.prosdent.2016.06.009.
[28] F. Bayindir, Y.Z. Bayindir, D.J. Gozalo-Diaz, A.G. Wee, Coverage error of gingival shade guide systems in measuring color of attached anterior gingiva, J. Prosthet. Dent. 101 (2009) 46–53, https://doi.org/10.1016/S0022-3913(08)60290-5.
[29] M. Ito, D.B. Marx, A.C. Cheng, A.C. Wee, Proposed shade guide for attached gingiva – a pilot study, J. Prosthodont. 24 (2015) 182–187, https://doi.org/10.1111/jopr.12195.
[30] L. Sala, A. Carrillo-de-Albornoz, C. Martín, A. Bascones-Martínez, Factors involved in the spectrophotometric measurement of soft tissue: a clinical study of interrater and intrarater reliability, J. Prosthet. Dent. 113 (2015) 558–564, https://doi.org/10.1016/j.prosdent.2014.11.003.
[31] R. Ghinea, L.J. Herrera, M.M. Pérez, A.M. Ionescu, R.D. Paravina, Gingival shade guides: colorimetric and spectral modelling, J. Esthet. Restor. Dent. 30 (2018) E31–E38, https://doi.org/10.1111/jerd.12376.
[32] C. Gómez-Polo, A.M. Martín Casado, M. Gómez-Polo, J. Montero, Colour thresholds of the gingival chromatic space, J. Dent. 103 (2020), 103502, https://doi.org/10.1016/j.jdent.2020.103502.
[33] D. Gouveia, B. Yilmaz, P. Cevik, W.M. Johnston, Using Kubelka-Munk reflectance theory to predict optimal pink composite thickness and shade with an opaqued PEEK background for a final gingival color: an *in vitro* study, Dent. Mater. 38 (2022) 1452–1458, https://doi.org/10.1016/j.dental.2022.06.027.
[34] C. Gómez Polo, J. Montero, M. Gómez Polo, A.M. Casado, Chromatic compatibility of two gingival shade guides with human keratinized gingiva, Int. J. Prosthodont. 36 (2023) 20–29, https://doi.org/10.11607/ijp.7389.
[35] P.C. Grieco, J.D. Da Silva, Y. Ishida, S. Ishikawa-Nagai, An *in vivo* spectrophotometric analysis of gingival acrylic shade guide, Materials 14 (2021) 1768, https://doi.org/10.3390/ma14071768.
[36] C. Gomez Polo, J. Montero, A.M. Martin Casado, Proposal for a gingival shade guide based on *in vivo* spectrophotometric measurements, J. Adv. Prosthodont. 11 (2019) 239–246, https://doi.org/10.4047/jap.2019.11.5.239.
[37] S. Maurice, C. Coachman, D. Garber, M. Calamita, H. Salama, G. Cabral, Prosthetic gingival reconstruction in a fixed partial restoration Part 1 introduction to artificial gingiva as an alternative therapy, Int. J. Periodont. Res. Dent. 29 (2009) 471–477.
[38] R.S. Amer, I. Chandrasekaran, W.M. Johnston, Illuminant effect on the coverage error of a gingiva-colored composite resin shade guide, J. Prosthet. Dent. 116 (2016) 770–776, https://doi.org/10.1016/j.prosdent.2016.03.016.
[39] F. Vailati, C. Belser, Artificial gingiva and implant supportes prosthesis in the esthetic zone: the pink power, Forum Implantol. 7 (2018) 1–17.
[40] P.D. Miller, Root coverage grafting for regeneration and aesthetics, Periodontol. 2000 1 (1993) 118–127.
[41] J. Ren, H. Lin, Q. Huang, Q. Liang, G. Zheng, Color difference threshold determination for acrylic denture base resins, Biomed. Mater. Eng. 26 (2015) S35–S43.
[42] M.M. Pérez, R. Ghinea, L.J. Herrera, F. Carrillo, A.M. Ionescu, R.D. Paravina, Color difference thresholds for computer-simulated human Gingiva, J. Esthet. Restor. Dent. 30 (2018) e24–e30, https://doi.org/10.1111/jerd.12373.
[43] C. Gómez-Polo, J. Montero, M. Gómez-Polo, A.M. Martin Casado, Comparison of the CIELab and CIEDE 2000 color difference formulas on gingival color space, J. Prosthodont. 29 (2020) 401–408, https://doi.org/10.1111/jopr.12717. Epub 2017 Dec 22.
[44] CIE (Commission Internationale de l'Eclairage). Annuaire, Roster, Register, Annexe au Bulletin CIE (París: bureau Central de la CIE). (PROCLUS, patrimonio Conicet); 1976.
[45] M.R. Luo, C. Guihua, The development of the CIE 2000 colour-difference formula: CIEDE2000, Color Res. Appl. 26 (2001) 340–350.
[46] J. Kleinheinz, A. Büchter, T. Fillies, U. Joos, Vascular basis of mucosal color, Head Face Med. 1 (2005) 4, https://doi.org/10.1186/1746-160X-1-4.
[47] B.S. Everitt, S. Landau, M. Leese, D. Stahl, Cluster Analysis, Wiley, 2011.
[48] S.J. Chu, R.D. Paravina, I. Sailer, A.J. Mieleszko, Color in Dentistry: a Clinical Guide to Predictable Esthetics, ed 1, Quintessence, Chicago, 2017.
[49] W.J. O'Brien, K.M. Boenke, C.L. Groh, Coverage errors of two shade guides, Int. J. Prosthodont. 4 (1991) 45–50.
[50] R.D. Paravina, M.M. Pérez, R. Ghinea, Acceptability and perceptibility thresholds in dentistry: a comprehensive review of clinical and research applications, J. Esthet. Restor. Dent. 31 (2019) 103–112, https://doi.org/10.1111/jerd.12465.
[51] J. Ren, H. Lin, Q. Huang, G. Zheng, Determining color difference thresholds in denture base acrylic resin, J. Prosthet. Dent. 114 (2015) 702–708, https://doi.org/10.1016/j.prosdent.2015.06.009.
[52] M.J. Naranjo, M. Gómez-Polo, C. Gómez-Polo, A. Celemin-Viñuela, Study of attached gingiva space color according to gender and age in Caucasian population, J. Esthet. Restor. Dent. (2023), https://doi.org/10.1111/jerd.13038. Mar 23.
[53] R.E. Jung, I. Sailer, C.H. Hämmerle, T. Attin, P. Schmidlin, *In vitro* color changes of soft tissues caused by restorative materials, Int. J. Periodontics Restor. Dent. 27 (2007) 251–257.
[54] E. Bressan, G. Paniz, D. Lops, B. Corazza, E. Romeo, G. Favero, Influence of abutment material on the gingival color of implant-supported all-ceramic restorations: a prospective multicenter study, Clin. Oral Implants Res. 22 (2011) 631–637, https://doi.org/10.1111/j.1600-0501.2010.02008.x.
[55] I. Sailer, A. Zembic, R.E. Jung, D. Siegenthaler, C. Holderegger, C.H. Hämmerle, Randomized controlled clinical trial of customized zirconia and titanium implant abutments for canine and posterior single-tooth implant reconstructions: preliminary results at 1 year of function, Clin. Oral Implants Res. 20 (2009) 219–225, https://doi.org/10.1111/j.1600-0501.2008.01636.x.
[56] A. Happe, V. Schulte-Mattler, S. Fickl, M. Naumann, J.E. Zöller, D. Rothamel, Spectrophotometric assessment of peri-implant mucosa after restoration with zirconia abutments veneered with fluorescent ceramic: a controlled, retrospective clinical study, Clin. Oral Implants Res. 24 (A100) (2013) 28–33, https://doi.org/10.1111/j.1600-0501.2011.02361.x. Suppl.
[57] R.E. Jung, C. Holderegger, I. Sailer, A. Khraisat, A. Suter, C.H. Hämmerle, The effect of all-ceramic and porcelain-fused-to-metal restorations on marginal peri-implant soft tissue color: a randomized controlled clinical trial, Int. J. Periodontics Restor. Dent. 28 (2008) 357–365.

[58] A. Hasegawa, I. Ikeda, S. Kawaguchi, Color and translucency of *in vivo* natural central incisors, J. Prosthet. Dent. 83 (2000) 418–423, https://doi.org/10.1016/s0022-3913(00)70036-9.

[59] S.J. Chu, R.D. Trushkowsky, R.D. Paravina, Dental color matching instruments and systems. Review of clinical and research aspects, J. Dent. 38 (2010) 2–16, https://doi.org/10.1016/j.jdent.2010.07.001.

[60] S. Paul, A. Peter, N. Pietrobon, C.H. Hämmerle, Visual and spectrophotometric shade analisys of human teeth, J. Dent. Res. 81 (2002) 578, https://doi.org/10.1177/154405910208100815. -558.