



BASIC RESEARCH:

Digital Analysis of Pre-Columbian Tooth Color: A Comparison of Shade Guides

Análisis digital del color dental precolombino: una comparación de guías de color

Isabel Ferreto-Gutiérrez DDS, MsC¹ <https://orcid.org/0009-0002-5367-3594>

Irene Valerio-Alfaro DDS, MsC² <https://orcid.org/0000-0002-7412-6330>

¹Research Center for Materials Science and Engineering (CICIMA), Department of Restorative Sciences, Dental School, University of Costa Rica, San José, Costa Rica.

²Department of Restorative Sciences, Dental School, University of Costa Rica, San José, Costa Rica.

Correspondence to: Isabel Ferreto-Gutiérrez, DDS, MsC - ISABEL.FERRETO@ucr.ac.cr

Received: 19-VIII-2025

Accepted: 22-VIII-2025

ABSTRACT: To describe the tooth color of pre-Columbian teeth from two archaeological sites in Costa Rica and to determine the most suitable digital shade guide for postmortem tooth color assessment. A total of 165 anterior teeth were assessed using a VITA EasyShade® V digital spectrophotometer. Color measurements were taken from the middle third of the buccal surface. Two digital shade guides, Vita Classical and Vita 3D-Master, were used to determine tooth shade. Statistical analyses included absolute and relative frequency calculations, along with bivariate analysis. According to the Vita Classical shade guide, 42% of the samples were categorized as color C4, followed by A3.5 and A4. Canines showed the highest percentage for A3.5 (57%) while A4 was equally distributed between canines and lateral incisors (36%). The highest percentage for C4 was observed in central incisors (51%). Using the Vita 3D-Master guide, 47% of the samples were categorized as color 5M3 (central incisors), followed by 4M3 and 3M3 (canines). Postmortem dental color can be effectively assessed using digital methods. Between the two shade guides, the Vita Classical is recommended for its higher precision. Additionally, central incisors in archaeological collections tend to exhibit greater saturation compared to the lateral incisors and canines. The use of digital spectrophotometry may contribute to the standardization of tooth color assessment in anthropological research. Additionally, the incorporation of the Vita Classical shade guide enhances accuracy in both historical and clinical contexts.

KEYWORDS: Pre-Columbian; Dentition; Vita Classical-3D-Master; Digital shade guide; Anthropology; Costa Rica.

RESUMEN: Describir la coloración dental de dientes precolombinos provenientes de dos sitios arqueológicos en Costa Rica y determinar la guía digital de colores más adecuada para la evaluación cromática post mortem. Se evaluó un total de 165 dientes anteriores mediante un espectrofotómetro digital VITA EasyShade® V. Las mediciones de color se realizaron en el tercio medio de la superficie vestibular. Para la determinación del tono dental se emplearon dos guías digitales de color: Vita Classical y Vita 3D-Master. El análisis estadístico incluyó el cálculo de frecuencias absolutas y relativas, así como análisis bivariado. Según la guía Vita Classical, el 42 % de las muestras se clasificaron como color C4, seguido por A3.5 y A4. Los caninos presentaron el mayor porcentaje de A3.5 (57 %), mientras que A4 se distribuyó equitativamente entre caninos e incisivos laterales (36 %). El mayor porcentaje de C4 se observó en incisivos centrales (51 %). De acuerdo con la guía Vita 3D-Master, el 47 % de las muestras se clasificaron como color 5M3 (incisivos centrales), seguido por 4M3 y 3M3 (caninos). El color dental post mortem puede evaluarse de manera eficaz mediante métodos digitales. Entre las guías de colores evaluadas, se recomienda el uso de Vita Classical por su mayor precisión. Además, los incisivos centrales en colecciones arqueológicas tienden a presentar mayor saturación en comparación con los incisivos laterales y los caninos. El uso de espectrofotometría digital puede contribuir a la estandarización de la evaluación del color dental en investigaciones antropológicas. Asimismo, la incorporación de la guía Vita Classical incrementa la precisión tanto en contextos históricos como clínicos.

PALABRAS CLAVE: Dentición; Precolombina; Vita Classical-3D-Master; Guía digital colores; Antropología; Costa Rica.

INTRODUCTION

Almost a century ago, researchers determined that an accurate and representative system for matching all perceptible tooth colors in dental prosthetics would require approximately 800 individual shade tabs (1). Currently, the color of dental pieces is a crucial factor in dental treatments, as it is an integral part of dental aesthetics. It has been documented that tooth color varies among different populations and is influenced by factors such as age, diet, smoking, rates of wear and certain medications (2-8). In studies conducted on pre-Columbian teeth, the description of color is not comparable in dental terms, as it is often characterized with terms such as yellowish, dark, pinkish, whitened, or mottled, among others (9-12). However, it is inferred that these teeth exhibited a darker color, possibly due to a diet based on cocoa, cultural practices, or the soil conditions in which they were buried (7,12-16).

From a dental perspective, as experts in tooth color matching, it is interesting to explore the classification of tooth color in these specimens, which we consider to be of great value within the field of archaeology. However, to date, no standardized categorization or description has been found in this field of research.

In dentistry, two main methods are used for determining the shade of teeth: visual assessment using shade guides and digital assessment through spectrophotometers that provide the highest overall accuracy and precision among different shade selection methods (17-23). One of the most commonly used and tested shade selection systems in dentistry is the Vita Classical guide (VC) of VITA Zahnfabrik (24-26), which is divided into four groups: A (orange), B (yellow), C (grayish yellow), and D (grayish orange). These hue levels are further categorized by different levels of chroma, represented by numbers from 1 to 4,

with 1 being the least saturated, ranging from A1 to D4. As the number increases, the value decreases, whereas the chroma increases simultaneously (27,28). Most natural teeth exhibit shades from groups A and B on this scale. However, in recent years, the same company has introduced a system that takes a more systematic approach, the VITA 3D-Master, (V3DM) of VITA Zahnfabrik, which presents 26 chromatic samples distributed into five groups designated by numbers: 1 (highest value) to 5 (lowest value). According to various authors, this scale offers greater coverage and uniformity in the distribution of samples, allowing for superior accuracy and ease in color selection (29,30).

The ability of the human eye to perceive colors is not precise enough to accurately distinguish its three dimensions. We perceive an impression of color but cannot separate brightness, saturation, and hue. Current intraoral devices allow for the physical measurement of intraoral tooth color using a standardized light source to analyze the tooth surface pixel by pixel (24,31). Spectrophotometers measure the color of an object through its reflected wavelength, and these data are obtained in the three-dimensional coordinates of the CIE-LAB system (32), which evaluates the light reflected by the teeth and presents the results according to the VC and V3DM scales. This enables a precise color assessment in compliance with the standards of both scales and allows for the presentation of chromatic results in different thirds, among other applications.

Reporting the color of pre-Columbian dentition in a standardized and reproducible manner would facilitate communication between anthropo-

logy and dentistry, allowing for the comparison of data between populations from past and present times, as well as the evolution of these over time. This would also enable comparisons with other archaeological findings at local, regional, and international levels.

As illustrated in Figure 1, three temporarily distinct geographical regions were identified within Costa Rica, reflecting patterns of human occupation and cultural development over time:

1. Greater Nicoya.
2. Central Archaeological Region (CAR), which includes:
 - A. Curridabat Phase from 300 A.D. to 700 A.D.
 - B. Transitional Phase from 700 A.D. to 1200 A.D.
 - C. Cartago Phase from 900 A.D. to 1550 A.D.
3. Greater Chiriquí(33)

This study was conducted using collections from two archaeological sites within the CAR, located south of present-day Cartago City, Costa Rica. The first site is Hacienda El Molino, C-27HM, where 34 box-type tombs were found. The second site is Agua Caliente, C-35AC, which includes a peripheral area with funerary sectors composed of 55 cemeteries containing groups of box-type tombs. In addition to their geographical proximity, both archaeological sites belong to the Cartago temporal phase (33-36).

The aim of this study is to describe the tooth color of pre-Columbian indigenous peoples and to determine the most suitable digital shade guide for postmortem tooth color assessment using the Vita

Classical and Vita 3D-Master guides. Hypothesis: The use of different digital shade guides does not significantly affect the assessment of postmortem tooth color in pre-Columbian dental remains.

Postmortem color differences are observed among central incisors, lateral incisors, and canines in pre-Columbian indigenous individuals.

MATERIALS AND METHODS

A total sample of 165 post-mortem teeth from pre-Columbian archaeological remains in Costa Rica, specifically from the sites Agua Caliente and Hacienda El Molino (C-35AC and C-27HM), housed at the National Museum of Costa Rica, was selected. All specimens were treated as sensitive material, handled with the utmost care and respect they deserve, in accordance with the Professional Code of Ethics of the International Council of Museums (ICOM) sections 2.5, 3.7, and 4.3 (37). The sample included 57 central incisors, 42 lateral incisors, and 66 canines, all identified as belonging to pre-Columbian indigenous peoples. The selection of teeth was based on their preservation status, ensuring that the pieces were intact and free of significant damage that could affect color measurements (Figure 5). Temporary teeth, teeth contaminated with soil, rootless teeth, and teeth with abnormal discolorations such as pink teeth were excluded from the study. For color measurement, the VITA Easyshade®V (VE) digital spectrophotometer (VITA Zahnfabrik, Bad Säckingen, Germany) was used (Figure 4). Measurements were taken on the middle coronal third of the buccal surfaces of each tooth to ensure consistency and reproducibility of the data, recording the color values in both

measurement systems (VC and V3DM). Each tooth was carefully cleaned using a cotton applicator and distilled water to remove surface debris that could interfere with color measurement. Subsequently, the teeth were air-dried for 24 hours. Color measurements were carried out in a room with controlled lighting to minimize variations due to ambient light. The teeth were placed on a stable sponge-like platform (opaque black background, 40 cm x 30 cm) that allowed for proper orientation and adequate exposure to the spectrophotometer. Each tooth or group of measured teeth was photographed along with its corresponding description. VE spectrophotometer was calibrated according to the manufacturer's instructions before each measurement.

The variables include color, assessed using two types of guides (VC and V3DM), the archaeological site from which the samples were collected, and the type of tooth on which the color was measured. The data obtained were entered into the statistical software SPSS version 25.0 (IBM, New York, USA). Descriptive statistical analyses were conducted to determine the absolute and relative frequencies of the different shades observed. A bivariate analysis using the Chi-square test was performed to evaluate the homogeneity of measurements between the VC and V3D guides and to calculate the frequency of shades for central, lateral, and canine incisors. A p-value <0.05 was considered statistically significant. A 95% confidence interval (CI) was applied to all significance tests. To ensure data reliability, quality control measures were implemented, including replication of measurements and cross-review of data by a second researcher.



Figure 1. Three geographic-temporal zones: Gran Nicoya, Central Archaeological Region (CAR), which includes a) Curridabat Phase (300 AD-700 AD), b) Transitional Phase (700 AD-1200 AD), c) Cartago Phase (900 AD-1550 AD), and Diquís region (38-40). Image created by L.A. Oruga.

RESULTS

This study analyzes the distribution of tooth colors assessed with the VE according to the scale used in the VC and V3DM guides at two archaeological sites C-27HM and C-35AC, as well as in different types of teeth: central incisors, lateral incisors, and canines. Most specimens come from the C-35AC site, and among the 165 samples, the majority (40%) are canines.

VC

As illustrated in Figure 2, out of the 16 possible shades in the Vita Classical guide, only five were identified in the sampled teeth, with A3.5, A4, and C4 being the most prevalent. These shades are characterized by orange and grayish-yellow tones with high saturation (23). This limited chromatic range may reflect shared genetic traits or environmental influences within the studied

population. This is consistent with Paravina *et al.*, who found that shades from Group A have the best match with human teeth, followed by shades from Groups C, B, and D, in that order (21,22).

DISTRIBUTION BY ARCHAEOLOGICAL SITE

Table 1 presents the distribution of the tooth shades A1, A3.5, A4, C4, and C5 observed at the archaeological sites, providing insights into the phenotypic characteristics and potential cultural or biological variations among past populations. At C-27HM, most of the teeth found belong to the C4 color, followed by A3.5. The colors A1 and C5 have minimal presence. At C-35AC, again, the most frequent color is C4, followed by A3.5, and unlike C-27HM, A4 is present with a prevalence of almost a third of the sample. Teeth with the highest and/or lowest dominant saturations were not found. There were no statistically significant differences in color variation between the archaeological sites.

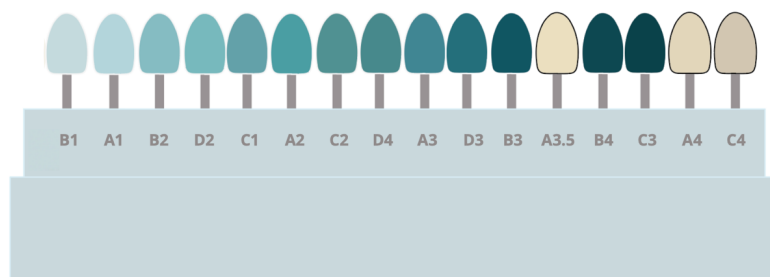


Figure 2. Image of the Vita Classical guide ordered by value, where the three most frequent colors of the sample A3.5, A4, and C4 are observed in white tones. Image created based on VITA Zahnfabrik, Bad Säckingen, Germany by Ferreto, Cristina.

Table 1. Distribution of color in the vita classic shade guide by archaeological site and tooth type.

	Total	Vita Classical Shade Color					p
		A1 n (%)	A3.5 n (%)	A4 n (%)	C4 n (%)	C5 n (%)	
Archaeological Site							0,347
C-27HM	39 (100)	1 (3)	10 (26)	8 (20)	19 (48)	1 (3)	
C-35AD	126 (100)	0 (0)	41 (32)	34 (27)	51 (41)	0 (0)	
Tooth type							0,001
Central	57 (100)	0 ^{ab} (0)	8 ^b (14)	12 ^{ab} (21)	36 ^a (63)	1 ^{ab} (2)	
Lateral	42 (100)	0 ^a (0)	14 ^a (33)	15 ^a (36)	13 ^a (31)	0 ^a (0)	
Canine	66 (100)	1 ^{ab} (1)	29 ^b (44)	15 ^{ab} (23)	21 ^a (32)	0 ^{ab} (0)	

DISTRIBUTION BY TOOTH TYPE

Table 1 also details the distribution of tooth shades according to tooth type-central incisor, lateral incisor, and canine-offering additional context for the analysis of phenotypic variation within the studied populations. Central incisors have a high prevalence of highly saturated grayish-yellow (C4), with lower frequencies of orange tones. The orange tones with minimal saturation are not present in the central teeth. In the lateral incisors, the most common color is orange with high saturation (A4), followed by the same less saturated hue and highly saturated grayish-yellow (A3.5 and C4). Teeth of the two predominant tones in very high or low saturations were not found. Canines show a prevalence of moderately saturated orange (A3.5), followed by highly saturated grayish-yellow and orange tones (C4 and A4).

Unlike the central incisors, the low-saturation orange tone (A1) is present in the canine sample, although in a low proportion.

When analyzing the results according to the value order of this guide-B1-A1-B2-D2-C1-A2-C2-D4-A3-D3-B3-A3.5-B4-C3-A4-C4, with B1 being the highest value and C4 the lowest value (28). We can note that the three most frequent tones in this study belong to the lowest luminance, as 4 out of 10 samples belong to the most saturated tone with the lowest luminance in this specific guide order. In general, 42% of the evaluated samples were categorized as highly saturated grayish-yellow (C4), the largest group. This was followed by orange tones (A3.5 and A4) in terms of frequency. When analyzing by tooth type, it was observed that the highest percentage of orange-colored specimens (A3.5) corresponded to canines, with 57%.

For the A4 orange color, the highest percentages were equally distributed between canines and lateral incisors, both reaching 36%. For the highly saturated grayish-yellow color (C4), the highest concentration was observed in central incisors, representing more than half of them. No samples of yellow (family B) or grayish-orange (family D) were found in the sample. The statistical analysis reveals significant differences in color distribution among the different tooth types ($p=0.001$).

V3DM

Following the pattern observed with the VC measurement, Table 2 shows the color distributions by the archaeological origin of the samples and the type of dental piece evaluated according to the V3DM guide scale. Of the 29 possible colors, samples from only seven colors were found, all in orange hue, in a combination of all the possible brightness levels in the guide (from 2 to 5) and only in chromas 1, 2, or 3, with a strong predominance of 4M2 and 5M3, both being oranges tending to lower brightness and medium to high saturation (23).

Figure 3 represents the V3DM guide with the seven most common tablets from the sample colored in a yellow tone.

DISTRIBUTION BY ARCHAEOLOGICAL SITE

At the archaeological site C-27HM, the only shade is orange 4M3, followed by 5M3, both with the lowest values on the scale. At the C-35AC archaeological site, the only color found is also orange with a trend from lower to higher value, always with the same saturation (5M3, followed

by 4M3 and 3M3). There is insufficient evidence to assert that there are significant differences in color distribution between these two archaeological sites ($p=0.302$).

DISTRIBUTION BY TOOTH TYPE

As described above, all the measured samples are of orange hue. The central incisors exhibit a high prevalence of the lowest value in the guide (5M3), with a trend towards increasing brightness (4M3) in two out of 10 samples. The same trend is followed by lateral incisors, from 5M3 to 3M3 in 12% of the sample. In canines, the trend is slightly different, as an equal number of pieces are of value 4 or 5 and then value 3, always with the same saturations and hues. As shown, the three-color tablets of this guide are repeated in the three groups evaluated. The statistical analysis does not reveal significant differences in color distribution among the different tooth types ($p=0.001$).

In general, almost half of the evaluated samples were classified as orange hue with the lowest possible value in the guide and the highest saturation described on this scale, constituting the largest group of samples in this category. The next most frequent colors tended to increase the amount of brightness (4M3 and 3M3). When analyzing the distribution by tooth type, it was found that the tones 4M3 and 5M3 showed the highest prevalence in canines. In contrast, for the 5M3 color, the highest proportion was observed in central incisors, with two-thirds of the specimens belonging to this category. No measured sample presented red or yellow hues, nor did they show medium or low saturations (e.g., 1 or 2) (23,26).

Table 2. Distribution of color in the vita 3D Master shade guide by archaeological site and tooth type.

	Total	Vita 3D Master Shade Color						p
		2M3 n (%)	3M3 n (%)	4M2 n (%)	4M3 n (%)	5M1 n (%)	5M2 n (%)	
Arqueological site								0,302
C-27HM	39 (100)	2 (5)	3 (8)	0 (0)	12 (31)	6 (15)	5 (13)	11 (28)
C-35AC	126(100)	4 (2)	19 (12)	1 (1)	49 (29)	9 (6)	5 (3)	78 (47)
Tooth type								0,001
Central	57 (100)	0 ^a (0)	3 ^a (5)	0 ^a (0)	11 ^a (19)	5 ^a (9)	1 ^a (2)	37 ^a (65)
Lateral	42 (100)	0 ^a (0)	5 ^a (12)	0 ^a (0)	14 ^a (33)	2 ^a (5)	3 ^a (7)	18 ^a (43)
Canine	66 (100)	4 ^a (6)	11 ^a (16)	1 ^a (2)	24 ^a (36)	2 ^a (3)	1 ^a (2)	23 ^a (35)

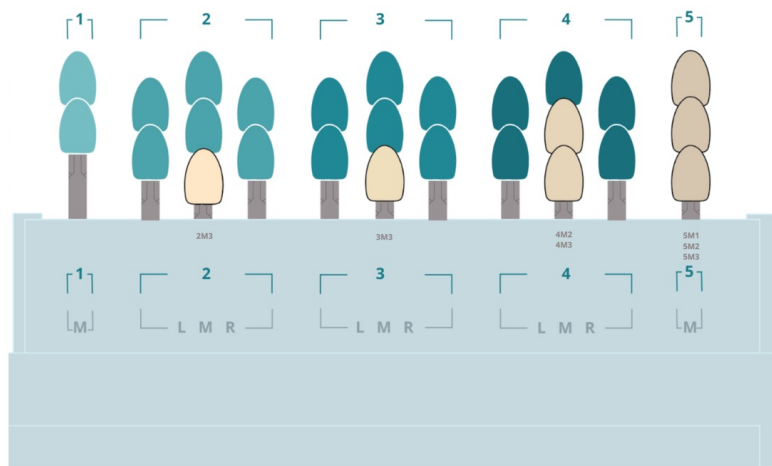


Figure 3. Representation of the 3D Master guide, where the seven most commonly found colors are highlighted in white tones. Image created based on VITA Zahnfabrik, Bad Säckingen, Germany, by Ferreto, Cristina.

DISCUSSION

The most significant finding of this research lies in the clear and well-founded recommendation to use the VC guide (A1-D4) for the assessment of dental color in post-mortem collections. This facilitates the clear and simple sharing of data with specialists in anthropology, an area where the eye may not be as trained as in dentistry, where clinicians regularly assess tooth color in their daily practice. This color guide is the most widely taught and used, (23,25,26) though the V3DM guide,

which uses a different scale from VC, can also be employed. As mentioned, in addition to visual methods, spectrophotometers and scanners with color selection modes specific to this function can be used (19). Our meticulous analysis revealed that the results obtained using the spectrophotometer with the VC guide scale are more accurate compared to those derived from the V3DM guide scale. This observation translates into greater consistency, detail, and reliability in determining dental color. Recent studies support this trend, showing better matches between selected shades

when using the VC guide (19). The lower dispersion of results in the VC guide highlights its ability to provide more reliable and reproducible measurements under these particular circumstances, likely due to the smaller number of color possibilities in each scale: 16 tabs for VC and 29 tabs for V3DM. A greater availability of shades leads to greater variation (19). This contrasts with what Paravina reported, which found that the V3DM color tabs were more evenly spaced compared to the VC guide (22).

This finding has significant implications for both clinical and forensic practice, suggesting that the choice of dental color guide can be a critical factor directly influencing the precision and validity of results obtained in post-mortem studies. For example, the discovery of pink teeth during post-mortem examinations has been documented for almost two centuries, (10) generally associated with violent deaths rather than natural causes. This phenomenon is of forensic relevance, as it is attributed to blood leakage following traumatic death, such as drowning, hanging, and poisoning (11). However, there have also been reports where pink tooth discoloration is a post-mortem alteration due to exposure to humid environments (14).

Feasibility tests have not been reported, as this tool has not been previously described in the literature. However, we consider its use in the archaeological field to be viable, as it provides a simple and rapid alternative compared to the learning curve required for visual color assessment in dentistry. In our initial assessment, we found several units with this discoloration that were excluded as they did not match any of the shades from the color guides used in the study. Additionally, the samples were molars or temporary anterior teeth that did not meet our inclusion criteria. Professionals in archaeology, dentistry,

and forensic medicine may carefully consider this recommendation when conducting dental color evaluations in forensic and identification cases.

This finding can complement the criteria described in the literature for estimating an individual's age, where, in addition to the presence of temporary or permanent teeth, the wear pattern of lower teeth, as described in the phases of attrition (8) as well as the detection of dental pathologies (13) or in populations where dental modifications were common, can provide a greater understanding of the cultural, genetic, and ecological structure of these groups through biomedical and anthropological studies (12).

The relevance of this finding within the context of research on tooth color in indigenous peoples, specifically from the Valle del Guarco region in Cartago, Costa Rica, lies in its importance for the precise and clear identification of these populations in anthropological and forensic studies. This is based on the discovery of graves excavated in the ground, constructed with limestone to demarcate the four sides of the tomb, and covered with flat slabs of rock (35). These three-dimensional formations, called stone box graves, were extensively described and date from 900 to 1500 A.D. (13,35) potentially extending back to the 6th century A.D. and possibly lasting until the 16th century, as noted by Vásquez (35). At the C-35AC site, a core area for religious activities and regional social functions, a significant number of large cemeteries for the ceremonial burial of society members close to the chiefs were found (35). This area, inhabited by Chibcha peoples, shows evidence of human presence dating back to 1500 B.C. (35) The C-27HM site, on the other hand, dates from 300 B.C. to 1000-1500 A.D. (13) and is believed to have been a cultural extension of C-35AC, forming a vast area with many

cemeteries. Table 3 details the dental collections from Costa Rica: their location, chronology, and the sample size used in this study, adapted from Cucina *et al.* (35).

Precision in determining dental color in these populations helps preserve and respect the cultural identity of indigenous peoples, as dental color may be influenced by genetic, dietary, and environmental factors unique to each community in time and space. Norr describes how traces of corn and beans, both carbonized grains, were found at the C-27HM site, as well as on tools such as metate and mortar grinding stones (13). In his study, the evaluation of stable carbon and nitrogen isotopes establishes individual consump-

tion patterns, addressing the contribution of corn, pineapple, cactus, manioc, cassava, cacao,(35) leguminous and non-leguminous plants, and vertebrate and invertebrate animals in these people's diets (13). The relationship between the types of food chromogens and dental color is well known; for example, Féliz-Matos *et al.* classify these pigmentations into three types, though the one relevant to this study is where chromogens bind to the dental surface, staining it (6).

These extrinsic factors range from tea and coffee (not yet present in Norr's description), tobacco (described by the Spanish during the conquest),(14) contact with metals, bacterial products, biofilm, poor oral hygiene, among others (14,15).

Table 3. Archaeological site, location, date and sample size of dental collections in Costa Rica.

Arqueological site	Location	Date	Sample size
C-27HM	Cartago	300 a.C 1500d.C	39
C-35AC	Cartago	1550d.C-SXVI	126



Figure 4. Complete skull from the C-27HM collection measured with Vita Easy Shade V. Photograph by the author.



Figure 5. Nine dental pieces from the same individual in the C-35AC collection, where the condition of the teeth and lesions on both teeth and bone can be observed. The classification assigned by the archaeologist in charge is visible. Photograph by the author.

THE COLOR

The current concept of dental aesthetics differs significantly from what was practiced in antiquity. The careful development of dental techniques has led to the production of teeth that align with the aesthetic patterns of contemporary societies, incorporating unity, symmetry, form, balance, color, structure, and function (16). In our study, within the V3DM scale, 65% of the central teeth studied were color 5M3, the lowest possible L^* value on this guide, with orange hue and saturation 3, making them the grayest and most saturated teeth in this measurement. Conversely, only 35% of canines matched this shade. In order of value on the VC guide, 63% of the grayest teeth (C4) were also central teeth, while less than half of the canines matched this tone. These two measurements reveal that, in the study of tooth color in indigenous peoples, central teeth are grayer and more saturated than canines, contrasting with the tones found in modern populations. Studies on the color distribution of natural teeth have reported that maxillary anterior teeth are slightly more

saturated than mandibular anterior teeth, and that maxillary central incisors have a higher value than lateral incisors and canines (1, 3).

Since there are significant differences in color distribution according to the type of tooth studied, it is suggested that biological, functional, morphological, or wear factors—whether physiological or intentional, as in the case of pre-Columbian dental mutilations in the Americas—may play a role in color variation (16).

This finding highlights the need for further research to explore the origin of pre-Columbian tooth color. It is crucial to determine whether the color is due to diet, the use of teeth as a third hand in manufacturing, burial conditions and geography (extrinsic discoloration), or due to ante-mortem pathologies or social practices (intrinsic discoloration). For now, this study uses a digitized color scale for pre-Columbian dental pieces, never applied, establishing a space for communication between archaeologists and dentists that can be replicated at other archaeological sites, in other

geographical latitudes, and in other contexts, always based on a color scale that will not vary with human perception and whose values are fixed within the color scale.

RECOMENDATIONS

For future studies, it is recommended to assess the applicability of this methodology in collaboration with archaeologists, as well as to analyze its reproducibility and standardization at both inter-operator and intra-operator levels. Additionally, the use of two-color guides is suggested to enhance the objectivity of measurements and facilitate result comparisons.

CONCLUSIONS

This study demonstrates the feasibility of describing post-mortem dental color using digital technologies. The VE spectrophotometer enabled precise evaluation of samples from the C-27HM and C-34AC archaeological sites, showing consistent identification of colors across central, lateral, and canine teeth.

Comparisons between guides revealed that the VC guide identified fewer colors with less dispersion, while the V3DM guide captured greater chromatic diversity and provided more detailed classification. Results also contradicted the hypothesis of higher saturation in canines, since central incisors often exhibited darker and more saturated shades.

These findings highlight the relevance of color analysis in anthropology, offering insights into biological and cultural factors and fostering interdisciplinary research that deepens our understanding of ancient populations in Costa Rica and the Americas.

CONFLICTS OF INTEREST: The author(s) declare(s) that there is no conflict of interest regarding the publication of this article.

FUNDING STATEMENT: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. It was conducted as part of the employment of the authors at the University of Costa Rica.

AUTHOR CONTRIBUTIONS STATEMENT: Conceptualization and design: I.F.G. and I.V.A.; Literature review: I.F.G. and I.V.A.; Methodology and validation: I.F.G. and I.V.A.; Formal analysis: I.F.G. and I.V.A.; Investigation and data collection: I.F.G. and I.V.A.; Resources: I.F.G. and I.V.A.; Data analysis and interpretation: A.L.S.; Writing-original draft preparation: I.F.G. and I.V.A.; Writing-review & editing: C.B.S.; Supervision: I.F.G. and I.V.A.; Project administration: I.F.G. and I.V.A.; Funding acquisition: -.

ACKNOWLEDGMENTS: We wish to thank Master Myrna Rojas-Garro, head of the Department of Anthropology and History, and Archaeologist Geissel Vargas-Madriral, both from the National Museum of Costa Rica, for their collaboration in providing access to the collections used in this study. We also wish to thank Dr. Andrea López Soto Msc for her collaboration in the statistical analysis of this study.

REFERENCES

1. Goodkind R.J., Schwabacher W.B. Use of a fiber-optic colorimeter for in vivo color measurements of 2830 anterior teeth. *J Prosthet Dent.* 1987 Nov; 58 (5): 535-42.
2. Vallitu P.K., Vallitu A.S.J., Lassila V.P. Dental aesthetics : a survey of attitudes in different groups of patients. *J Dent.* 1996; 24 (5): 335-8.

3. Joiner A. Tooth colour: A review of the literature. *J Dent.* 2004; 32 (SUPPL.): 3-12.
4. Davis L.G., Ashworth P.D., Spriggs L.S. Psychological Effects of aesthetic dental treatment. *Journal of Dentistry* . 1998; 26: 547-54.
5. Chu S.J., Trushkowsky R.D., Paravina R.D. Dental color matching instruments and systems. Review of clinical and research aspects. *Journal of Dentistry.* 2010.
6. Féliz-Matos L., Miguel Hernández L., Abreu N. Dental Bleaching Techniques; Hydrogen-carbamide Peroxides and Light Sources for Activation, an Update. Mini Review Article. Vol. 8, *The Open Dentistry Journal.* 2014.
7. Valerio-Alfaro Irene. dental aeStheticS of the Pre-columbian PoPulationS baSed on the Study of the viSual PatternS. *Rev Cient Odontol.* 2012; 8 (2).
8. Lovejoy C.O. Dental Wear in the Libben Population: Its Functional Pattern and Role in the Determination of Adult Skeletal. Age at Death. *AJPA* Vol. 68, 1985.
9. Rodríguez-Fernández L., Ruvalcaba-Sil J.L., Ontalba-Salamanca M.A., Rom An-Berrelleza J.A., Gallardo M.L., Grimaldi D.M., et al. Ion beam analysis of ancient Mexican colored teeth from archaeological sites in Mexico City. *Nucl Instrum Methods Phys Res B.* 1999; 150: 663.
10. Arias C.G., Iriarte M.A.F., Outes M.S., Zemborain C.R., Rannelucci L.R., Casadoumecq A.C. Clinical and Forensic Aspects of the Pink Color of the Teeth. Case Report. *Rev Fac Odontol Univ Buenos Aires.* 2023; 38 (88) (8).
11. Beeley J.A., Harvey W. Pink Teeth Appearing as a Post-Mortem Phenomenon. *Journal of the Forensic Science Society.* 1973; 13 (4): 297-305.
12. Valerio-Alfaro MSc I., Chavarría-Bolaños MSc, PhD D. Pre-Columbian Dental Modifications in Costa Rica: A Study of Three Archaeological Sites. *Odovtos - International Journal of Dental Sciences.* 2017 Mar 2; 19 (1): 69.
13. Norr L.C. Nutritional consequences of prehistoric subsistence strategies in lower Central America. PhD thesis, University of Illinois; 1991.
14. Dumser T.K., Türkay M. Postmortem changes of human bodies on the bathyal sea floor - Two cases of aircraft accidents above the open sea. *J Forensic Sci.* 2008 Sep; 53 (5): 1049-52.
15. Olivera, J. R. Breve historia del origen del tabaco en América y su difusión en Europa. *Arqueología y Sociedad* ,1970, 2, 55-58.
16. Perdigão J. Tooth Whitening An Evidence-Based Perspective Springer Nature. Second Edition. 2023.
17. Gómez-Polo C., Montero J., Gómez-Polo M., de Parga J.A.M.V., Celemin-Viñuela A. Natural Tooth Color Estimation Based on Age and Gender. *Journal of Prosthodontics.* 2017 Feb 1; 26 (2): 107-14.
18. Chang J.Y., Chen W.C., Huang T.K., Wang J.C., Fu P.S., Chen J.H., et al. Evaluating the accuracy of tooth color measurement by combining the Munsell color system and dental colorimeter. *Kaohsiung Journal of Medical Sciences.* 2012 Sep; 28 (9): 490-4.
19. Liberato W.F., Barreto I.C., Costa P.P., de Almeida C.C., Pimentel W., Tioosi R. A comparison between visual, intraoral scanner, and spectrophotometer shade matching: A clinical study. *Journal of Prosthetic Dentistry.* 2019 Feb 1; 121 (2): 271-5.
20. Tabatabaian F., Beyabanaki E., Alirezai P., Epakchi S. Visual and digital tooth shade selection methods, related effective factors and conditions, and their accuracy and precision: A literature review. Vol. 33, *Journal of Esthetic and Restorative Dentistry.* John Wiley and Sons Inc; 2021. p. 1084-104.

21. Paravina R., Powers J., Fay R.M. Color comparison of two shade guides. *Int J Prosthodont.* 2002; Vol 15 (1), 73-78.
22. Paravina R.D., Majkic G., Imai F.H., Powers J.M. Optimization of tooth color and shade guide design: Clinical research. *Journal of Prosthodontics.* 2007 Jul; 16 (4): 269-76.
23. Chu S., Paravina R., Devigus A., Mieszko A. *Fundamentals of Color matching: Shade matching and communication in esthetic dentistry.* second edition. Quintessence Publishing; 2010.
24. Jan Hajtó. Anteriores Dientes Naturalmente Hermosos. *ALMOCA*; 2020. 207-210 p.
25. Igiel C., Lehmann K.M., Ghinea R., Weyhrauch M., Hangx Y., Scheller H., et al. Reliability of visual and instrumental color matching. *Journal of Esthetic and Restorative Dentistry.* 2017 Sep 1; 29 (5): 303-8.
26. Chu S.J., Trushkowsky R.D., Paravina R.D. Dental color matching instruments and systems. Review of clinical and research aspects. In: *Journal of Dentistry.* 2010.
27. Brewer J.D., Wee A., Seghi R. Advances in color matching. Vol. 48, *Dental Clinics of North America.* 2004. p. 341-58.
28. Anusavice K., Shen C., Rawls R. *Phillips Science of Dental Materials.* 12th ed. Elsevier.
29. Hassel A.J., Zenthöfer A., Corcodel N., Hildenbrandt A., Reinelt G., Wiesberg S. Determination of VITA Classical shades with the 3D-Master shade guide. *Acta Odontol Scand.* 2013 May; 71 (3-4): 721-6.
30. Hassel A., Hassel A.J., Dent M., Koke U., Schmitter M., Beck J., et al. Clinical Effect of Different Shade Guide Systems on the Tooth Shades of Ceramic-Veneered Restorations *International Journal of Prosthodontics.* 2005; 18 (5): 422-426.
31. Brandt J., Nelson S., Lauer H.C., von Hehn U., Brandt S. In vivo study for tooth colour determination-visual versus digital. *Clin Oral Investig.* 2017 Dec 1; 21 (9): 2863-71.
32. Schmeling DDS, MS, PhD M. *Color Selection and Reproduction in Dentistry. Part 3: Visual and Instrumental Shade Matching.* Odovtos - International Journal of Dental Sciences. 2017 Mar 2; 19 (1): 23-30
33. Corrales Ulloa F. *Deep Story of Costa Rica.* 2022 [cited 2024 Sep 23]. *Deep History.* Available from: <https://www.museocostarica.go.cr/divulgacion/articulos-educativos/arqueologia/historia-profunda/>
34. Salazar Camacho M. *Representaciones De Estamento Basal De La Sociedad En El Sitio Agua Caliente C-35 AC: Un Acercamiento A Través De Las Prácticas Funerarias Y De Los Restos Humanos De La Fase Cartago (900-1550 D.C.)* Universidad de Costa Rica, 2013. 333 (tesis de licenciatura).
35. Cucina A., Aguilar-Bonilla M., Coppa A., Ortega-Muñoz A. Prehispanic Costa Rica: A preliminary analysis of inner population affinities and its relationships with Mesoamerica and northern South America. *J Archaeol Sci Rep.* 2024 Jun 1; 56: 1-13
36. Peytrequín Gómez J. *Agua Caliente, Espacialidad y Arquitectura en una Comunidad Nucleada Antigua de Costa Rica.* Cuadernos de antropología. 2009; (19): 31-55.
37. Rojas-Garro M. *Manual de Normas y Procedimientos para el Tratamiento y el Manejo de las Colecciones Arqueológicas con Contexto.* 1st ed. San José: Museo Nacional de Costa Rica; 2016.
38. Los Angeles County Museum of Art. LACMA. [cited 2025 Apr 7]. Vessel, Costa Rica, Guanacaste, Nicoya, 1000-1500 Ceramics. Available from: <https://collections.lacma.org/node/240174>
39. Matarrita D. *Nación .* 2016 [cited 2025 Apr 7]. *El Diquís, las Esferas de Piedra y su Valor*

Cultural Universal. Available from: <https://www.nacion.com/viva/cultura/el-diquis-las-esferas-de-piedra-y-su-valor-cultural-universal/VBF5ODRHJVHRFBJJUHFCF-TJLAM/story/>

40. Sánchez V., Sánchez J. Museo Nacional de Costa Rica. 2024 [cited 2025 Apr 7]. Cementerio de Tumbas de Cajón. Available from: <https://www.museocostarica.go.cr/divulgacion/cementerio-de-tumbas-de-cajon/>