SCIENTIFIC RESEARCH REPORT

International Dental Journal 2015; 65: 227–234

doi: 10.1111/idj.12176

Correlation of natural tooth colour with aging in the Spanish population

Cristina Gómez Polo[1], Miguel Gómez Polo[2], Javier Montero[1], Juan Antonio Martínez Vazquez De Parga[2] and Alicia Celemin Viñuela[2]

[1]*Departament of Dentistry, School of Medicine, University of Salamanca, Salamanca, Spain;* [2]*Departament of Orofacial Prosthesis, Faculty of Dentistry, University Complutense of Madrid, Madrid, Spain.*

Objectives: To analyse natural tooth colour in the Spanish population according to the colour coordinates lightness (L*), chroma (C*), hue (h*), red–green axis (a*) and yellow–blue axis (b*) in order to quantify the correlation and changes of tooth colour with age and sex. **Methods:** Natural tooth colour was measured in a sample of 1,361 Spanish participants of both sexes distributed within an age range of 16 to 89 years. The Easyshade Compact spectrophotometer was used and the CIELAB and CIELCh systems were followed. **Results:** Pearson's bivariate correlations between age and colour coordinates were highly significant for L* ($r = -0.674$, $P \leq 0.001$), h* ($r = -0.468$, $P \leq 0.001$) and C* ($r = 0.417$, $P \leq 0.001$). The correlation between age and colour coordinates was stronger for men than for women, for all colour coordinates. The results showed that C*, b* and a* increased by 0.60, 0.56 and 0.26 units/year on average, respectively, whereas L* and h* decreased progressively with age (by 0.60 units/year, on average), and colour differences increased in a systematic way as the gap between the ages being compared grew wider. **Conclusions:** The strongest correlation was found between age and L*, then between age and h* (both inverse relationships) and then between age and a*, C* and b* (direct relationships). In addition, a similar degree of change in the colour coordinates L*, C* and h* (of 0.60 units/year on average) was observed for natural tooth colour. Knowledge of the chromatic range of natural teeth may help to choose colour for the replacement of missing elements.

Key words: *Natural tooth colour, age, gender, CIELCh, spectrophotometer, Pearson's correlation*

INTRODUCTION

Colour is one of the most important parameters when it comes to a patient's assessment of the quality of dental restorations. In addition to the morphofunctional restoration of teeth, demands for dental treatment that can restore, or even improve, natural appearance increase on a daily basis[1]. Colour perception is a phenomenon that can be described as a physical concept susceptible to measurement and study, and it depends on several factors that will be examined below. This phenomenon should be analysed as an interrelated entity in which changes in the components responsible for colour result in altered colour perception[2,3].

It has been reported that 23% of British adults are not satisfied with the natural colour of their teeth[4]; this percentage increases to 34%[5] in the USA, 52.6% in China[6] and 65.9% in Saudi Arabia[7]. Tooth colour is considered to affect appearance through its influence on the perception of personal features by others, and hence could add another dimension to the concept of the perfect smile[8]. Generally speaking, the colour change of natural teeth is an important factor that influences an individual's perception of appearance. There may be a negative effect for some individuals whose teeth become darker and yellower with time[6]. Teeth consist of three types of tissue – enamel, dentine and pulp – and their natural colour depends on their thickness, composition and structure, which are ultimately responsible for a tooth's complexity in terms of optical appearance. All three parameters evolve with time, affecting the tooth colour of an individual. Each of these tissues has different optical properties[9]. Moreover, in this research, other variables that have not been studied, such as eating habits, tobacco smoking or the ingestion of different types of drugs, which could also modify natural tooth colour.

Currently, there are many methods for measuring tooth colour, ranging from subjective visual comparison with acrylic or porcelain colour guides, to objective shade measurement using spectrophotometers. Spectrophotometers are used to measure wavelengths and have been employed for measurement of the visible spectrum in extracted and vital teeth[9–13]. Nevertheless, in 2002, Tung *et al.*[14] reported that the widespread use of spectrophotometers in dentistry has been hampered by their complexity, high price and, above all, the difficulty in using them to measure tooth colour *in vivo*. An object's colour depends on three factors: the spectral composition of the light source; the physical properties of the object being observed; and the sensory properties of the observer's visual system.

In 1976, the Standard Commission Internationale de l'Éclairage (CIE) defined colour space through the ordinate coordinates on the three space axes: L*, a colour's value (lightness), is determined by the amount of grey it contains, which is equivalent to lightness/darkness and ranges from perfect white (L* = 100) to complete black (L* = 0); a*, red–green measurement axis (a positive a* indicates the amount of red and a negative a* indicates the amount of green); and b*, yellow–blue measurement axis (a positive b* indicates the amount of yellow and a negative b* indicates the amount of blue). The CIE 1976 L* a* b* system identifies the components of the cylindrical coordinates CIE L*, C* and h*: lightness, chroma and hue, respectively[15]. The L* parameter does not change because it corresponds to the vertical axis. The transformation of a* and b* into chroma (C*) and hue (h*) is obtained through mathematical formulae. h* is the first colour dimension and it is associated with a colour's dominant wavelength. Hue is the quality by which colour families can be distinguished from one another. When the value of the h* coordinate is 90° it corresponds to yellow, when h is 0° it corresponds to red, when h* is 270° it corresponds to blue and when h* is 180° it corresponds to green. Chroma is the measurement of colour and the amount of saturation in a colour's hue. The CIELCh colour scale is a colour standard developed by CIELAB. CIE L*, C*, h* is a polar representation of the CIE L*, a*, b* rectangular coordinate system. It describes colour in the same way in which colour is communicated verbally in terms of L*, C* and h*. The L*C*h* expression offers an advantage over CIELAB in that it is very easy to relate to earlier systems based on colour dimensions. In this way, the L*, C* and h* coordinates are more intuitive and correspond to the three colour dimensions lightness, chroma and hue, respectively.

It has been reported that the colour of natural teeth becomes darker over time[6,9,11,16], but the degree of correlation and change with the colour coordinates (L*, C*, h*, a* and b*) has not yet been assessed. The null hypothesis tested proposes that lightness, hue and chroma are not modified by gender or age. The purpose of this study was to analyse tooth colour in the Spanish population according to the L*, C* and h* colour coordinates, to quantify its change according to age and gender.

MATERIALS AND METHODS

The study was based on the measurement of 1,361 maxillary central incisors from a sample of White Spanish people: 671 men and 690 women, 16–89 years of age, distributed homogeneously according to gender and age (described in more detail below). One clinician (a 30-year-old woman with 8 year's experience) was responsible for making the measurements, always using the same Easyshade Compact spectrophotometer. This clinician was instructed in the theory and practice of use of the Easyshade compact over a 2-day period. The sample was divided, according to age, into eight groups: 16–19 years; 20–29 years; 30–39 years; 40–49 years; 50–59 years; 60–69 years; 70–79 years; and 80–89 years. The clinician collected data from different geographical locations in Spain and indeed a large part of the Spanish territory was covered: Cáceres; Salamanca; Oviedo; Vigo; Toledo; Badajoz; Valladolid; Burgos; León; Soria; Zamora; Palencia; Ciudad Real; Ávila; Madrid; and Zaragoza. All participants were evaluated at the Department of Prosthodontics, School of Odontology, Complutense University of Madrid, Spain.

All natural maxillary central incisors were healthy, with no history of restoration or bleaching, and were cleaned before tooth colour was measured by spectrophotometry. Additionally, the colour of the surroundings was neutralised with a grey cloth. All colour recordings were carried out under D65 daylight fluorescent tubes with a light intensity of 1,500 lux. A standardised protocol for colour evaluation was adopted for all patients, and all recordings were performed in the same room under standardised lighting conditions. The spectrophotometer used was a Vita Easyshade Compact (Vita-Zahnfabrik, Bad Sackingen, Germany), which had previously been subjected to a reliability test to check its temporal stability and interexaminer reliability. This involved five operators recording measurements for three maxillary incisors (with extreme colours) three times using the Easyshade compact. These recordings were repeated five different times and the data were studied statistically. The results were homogeneous and hence the spectrophotometer used can be considered to be reliable.

Before the recordings were made, a hygienic protector was placed on the probe tip and the lamp was calibrated according to the indications of the manufacturer. Then, after calibration of the probe tip, it was placed in contact with and perpendicular to, the middle third of the facial surface of the tooth and the first result that coincided twice was recorded, following the manufacturer's instruction. All incisors were recorded in the 'Single Tooth' mode. For instrumental colour measurement, the middle third of the tooth appeared to provide the optimal representation of tooth colour[17]. The first shade that matched twice was recorded according to the CIELAB/CIELCh space coordinates L*, C*, h*, a* and b*. The results were obtained exclusively with a spectrophotometer, which guaranteed their objectivity. The Research Ethics Committee of the San Carlos Clinic (Madrid) gave a positive evaluation of the protocol used in this study; that is, it met the standards of good clinical practice. The present research was conducted in full accordance with the World Medical Association Declaration of Helsinki and was independently reviewed and approved by the Research Ethics Committee of the San Carlos Clinic (Madrid). All participants were asked to read and sign an informed consent form for participation in the present study. In this, a quiet, private place was found to explain the consent process to all the patients and/or their parents (if the patient was under 18 years of age); relevant information was provided in simple language, understanding was checked, the patient was encouraged to ask questions, and their written signature, or that of their parents (for participants under 18 years of age), was obtained. The program used for statistical analysis of the results and for creating graphs was SAS 9.1.3 (SPSS Inc., Chicago, IL, USA).

RESULTS

To check how lightness or value, hue and chroma become altered with age in both genders, the sample was divided into the eight different age groups described in Materials and Methods. The chi-square test for homogeneity, with $P > 0.05$, revealed that there were no statistically significant differences among groups regarding age and gender (χ^2 = 4,550; 7df; n = 1,361; P = 0.715) (*Table 1*).

The strongest correlation between age and colour coordinates was found for the L* variable, with a negative correlation of −0.674; the second strongest correlation was for h*, with a negative correlation of −0.468. It was observed that all correlations between age and the colour coordinates, in both men and women, were significant ($P \leq 0.001$). It was also observed that the correlations were slightly stronger in men than in women (*Table 2*). Direct correlations (i.e. when age increases the variables also increase) were found for C*, a* and b*.

The minimum and maximum values were 47.0 and 91.3 for L*, 5.9 and 49.8 for C* and 67.5° and 112.0° for h*. For a*, the minimum was −3.0 units and the maximum was 16.1 units; and for b*, the minimum was 6.0 units and the maximum was 47.3 units. The interval of L* (L*max–L*min) was 44.3 units; that of C* (C*max–C*min) was 43.9 units; and that of h* (h*max–h* min) was 44.5 units[18].

The age range studied, of 16–89 years, spans 73 years (89–16 = 73). The change of tooth colour during this period was homogeneous and progressive: on average, L* and h* decreased by 0.60 units/year and C* increased by 0.60 units/year. In other words, the three colour coordinates h*, L* and C* varied by approximately 0.60 units/year. Following the same reasoning, a* and b* increased, on average, by 0.26 units and 0.56 units/year, respectively.

Table 3 shows the average values of the coordinates studied in men and women. The average values of L* and h* were higher in women than in men, (by 2.53 and 1.97 units, respectively). By contrast, the average values of C*, a* and b* were higher in men than in women (by 3.16 units, 0.91 units and 3.11 units, respectively). From the average values of the coordinates it can be calculated that men had a less luminous natural tooth colour, with a larger amount of red and yellow and with a higher degree of intensity.

Table 1 Distribution of study sample according to age and sex

Age group(years)	Men(n)	Women(n)
16–19	70	76
20–29	136	141
30–39	55	59
40–49	102	109
50–59	80	81
60–69	148	128
70–79	64	70
80–89	16	26

Table 2 Pearson's correlation (r) between age (in the total study sample and in male and female subsamples) and colour coordinates

Colour coordinate	Gender	r
L*	Total sample	−0.674**
	Men	−0.699**
	Women	−0.672**
C*	Total sample	0.417**
	Men	0.491**
	Women	0.365**
h*	Total sample	−0.468**
	Men	−0.505**
	Women	−0.451**
a*	Total sample	0.460**
	Men	0.500**
	Women	0.472**
b*	Total sample	0.417**
	Men	0.490**
	Women	0.365**

**P-value ≤ 0.001. Highly significant correlation.a*, measurement along the red–green axis; b*, measurement along the yellow–blue axis; C*, chroma; h*, hue; L*, lightness.

Table 3 Average values of the color coordinates lightness (L*), chroma (C*), hue (h*) and measurements along the red–green axis (a*) and yellow–blue axis (b*) in men and women

Gender	*n*	Age (years)	Colour coordinates				
			L*	C*	h*	a*	b*
Men	671	16–89	74.98	21.53	89.90	0.59	21.42
Women	690	16–89	77.51	18.37	91.87	−0.32	18.31

Figures 1–3 represent the different colour dimensions with a confidence interval of 95%. The polar coordinates (L*, C* and h*) were chosen owing to their greater correspondence to the three colour dimensions.

Changes in L*, with age, are shown in *Figure 1*. A progressive decrease of L*, with increasing age, was observed for both men and women, from 85 L* units in the age group < 19 years to 60 L* units for men and 68 L* units for women in the age group 80–89 years. It was further observed that L* was slightly higher in women than in men in all age groups analysed, except for individuals under 19 years of age, in whom almost no differences were seen.

The findings for C* are shown in *Figure 2*. The 95% confidence interval of C* for both men and women was small in the <19 years and 20–29 years age groups, after which a progressive increase of C* with age was observed. In all age groups, C* was slightly higher in men. For the 40–49 years age group, the 95% confidence interval of C* was approximately

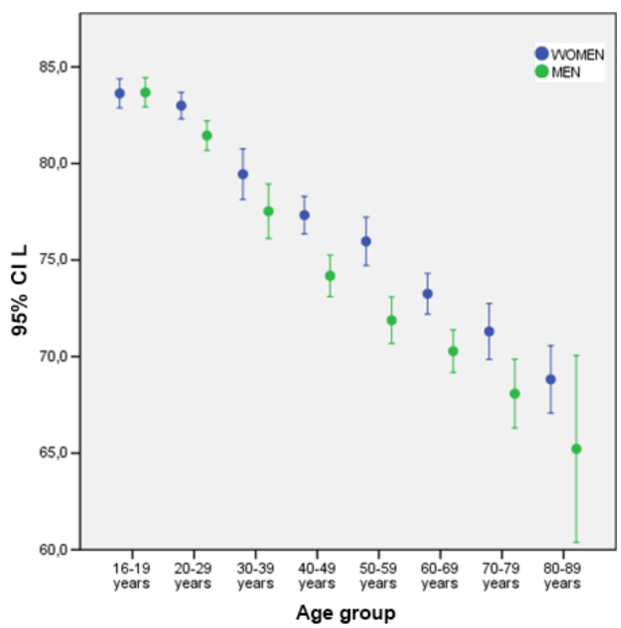

Figure 1. Change in the lightness (L*) coordinate with age. 95% CI, 95% confidence interval.

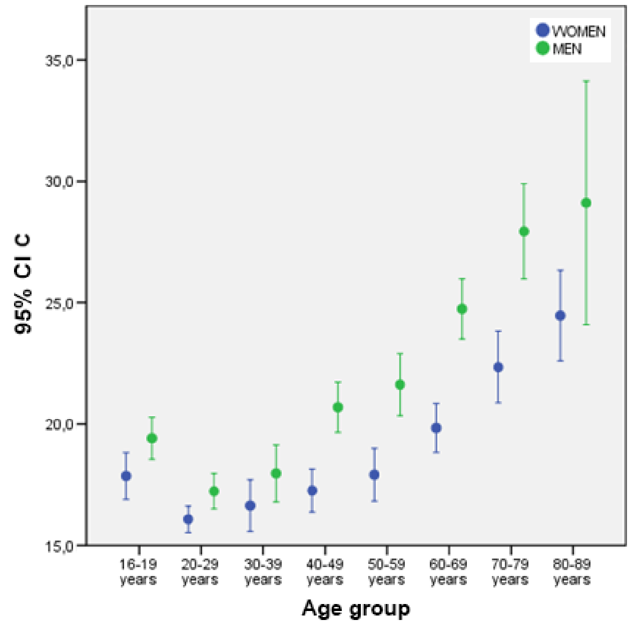

Figure 2. Change in the chroma (C*) coordinate with age. 95% CI, 95% confidence interval.

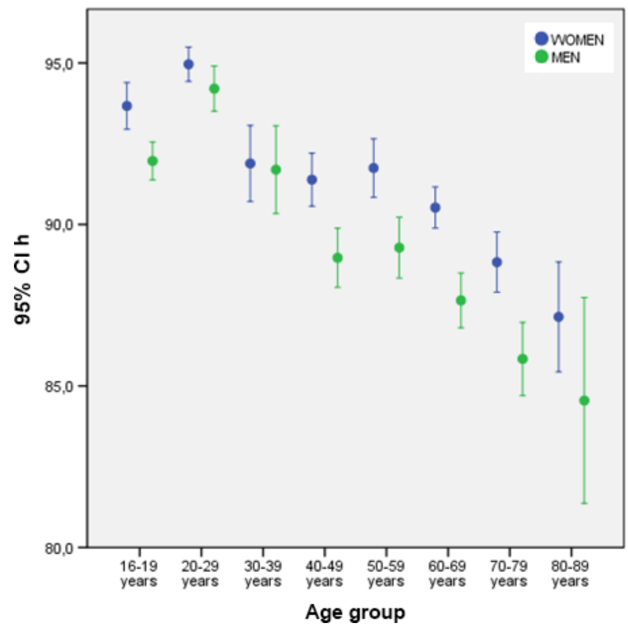

Figure 3. Change in the hue (h*) coordinate with age. 95% CI, 95% confidence interval.

18–22 for men and 17–19 for women. Of note, for men in the 80–89 years age group, the 95% confidence interval of C* was broad, ranging from 24 to 34.

Finally, h* (*Figure 3*), was found to increase up to the age of 30, and thereafter decreased progressively with age in a uniform manner in men and women. Similarly to L*, h* values were slightly higher in women than in men. Moreover, similarly to L* and

C*, a large 95% confidence interval was observed for h* in subjects 80–89 years of age, especially in men.

DISCUSSION

The limitations of this study may derive from the spectrophotometer used, as well as from the populations selected. The present work was transversal and descriptive, and the size of the sample was sufficient, even though not all groups were of the same size owing to the population sampling system employed. The size of the present sample matched the minimum *n* required to achieve the statistical conditions necessary to represent the Spanish population (confidence level 95.5%; accuracy 3% and P = q = 0.50). The deficiency is not found in the number of individuals included in the study, but in the actual composition of the sample, which does not represent the whole of the Spanish territory. Even though the sample does not represent the whole Spanish geographical area, the results obtained suggest that the approach used is sound.

Many publications on natural teeth colour have used a sample similar in size, or even smaller, than that of the present study, to draw conclusions for different populations: South-East Asia (n = 162)[19], Buffalo (n = 501)[20]; Japan (n = 87)[9]; other studies related to natural tooth colour (n = 195)[21], (n = 195)[22]; and Spain (n = 600) [23].

No clear limits for the coordinates of natural dentition have been established. Most authors have studied the natural dentition through the L*, a* and b* coordinates[5,9,19,22–26]. Others, such as Schmitter *et al.*[27], used the L*, C*, h* system. The CIELCh model uses the basic CIELAB information, but presents the graphical information with a focus on chroma and hue, which may be easier to understand visually than the CIELAB system[28]. This is why polar coordinates (L*, C* and h*) were used in the present study (*Figures 1–3*). For men in the 80–89 years age group, a very broad 95% confidence interval was observed for L*, C* and h* (*Figures 1–3*), perhaps because the sample sizes were relatively small.

Previous studies are not homogeneous regarding the age of the participants or the electronic device used for data collection. Yuan *et al.*[20] used the Easyshade (Vita-Zahnfabrik) spectrophotometer and a minimum age of 18 years for participants. Cocking *et al.*[22] and Eiffler *et al.*[21] also used the same spectrophotometer and the age ranges studied were 54–56 years and 73–75 years, respectively. Hasegawa *et al.*[9] used a spectroradiometric measurements and the subjects of this study were 13–84 years of age. Rubiño *et al.*[23] used a colorimeter and participants were 15–50 years of age. Zhu *et al.*[19] used a system of fiberoptic spectrophotometry and the age range of participants was 20–73 years.

In the results of the present study (minimum L* = 47.0 units; maximum L* = 91.3 units) broadened the range of the L* variable in comparison with that of other work. For example, Yuan *et al.*[20] recorded a minimum L* value of 58.7 units and a maximum L* value of 88.7 units. This difference might be because the age of 58% of the sample was 21–30 years. Cocking *et al.*[22] published a minimum L* value of 52.0 units and a maximum L* value of 90.0 units, whereas Zhu *et al.*[19] recorded a minimum L* value of 42.3 units (i.e. lower than that of the present study) and a maximum L* value of 67.4 units.

In the present study, the minimum value of a* was −3.0 and the maximum was 16.1. Cocking *et al.*[22] described minimum and maximum values of a* units of −4.1 and 13.3, respectively. Zhu *et al.*[19] found values of a* to range from −4.7 to 1.3, and Yuan *et al.*[20] reported values of a* to range from −3.6 to 7.0. The b* coordinate was analysed in a similar way: the minimum value found in the present work was 6.0 units and the maximum was 47.3 units. For other authors, the values reported varied from 3.7 to 37.3 units[20], from 10 to 41.7 units[22] and from 1.8 to 20.2 units[23]. Comparing the results of the C* and h* coordinates was more complex. The results of this work, in many cases, broaden the variability of colour coordinates, perhaps because the age range analysed was larger.

Noticeable differences were found between studies in the limits of the L*, a* and b* coordinates in natural dentition. This may be a result of the lack of methodological standardisation and differences in the populations studied. The variability in the colour coordinates that, according to the manufacturer (Vita-Zahnfabrik), occurs in natural dentition, is encompassed within L* of 65–90 units, C* of 5–30 units and h* of 70–90°. Our results slightly extend these parameters for the three colour coordinates. In the Spanish population, as in the Buffalo population[20], the space of natural tooth colour is encompassed the 3D Master manufacturer's colour space.

One of the few studies based on the Spanish population was published by Rubiño *et al.*[23]. Their results were analysed according to the CIELAB measurement system and are expressed in terms of L*, a* and b*, the mean of the results obtained being L* = 67.6, a*= 4.3 and b*=12.1. The study did not take into account any gender or age distinctions. Thus, the statistical adjustment of 95% of their results to the colour space affords an ellipse centred at a*= 4.3 and b*=12.1. As an additional observation, the authors reported that the ellipse did not include points a*= 0 and b*=0, which would correspond to white. They also stated that, according to the graph, teeth covered the colour area that approaches yellow. However, in the present study the mean values for the three coordinates were different (*Table 3*). We consider three plausible explanations for this variation: first, the samples used were different (Rubiño *et al.*[23] worked with 600 participants of 15–50 years of age); second, in the work of Rubiño *et al.*[23], tooth colour was measured using a colorimeter; and, third, in the present study, fluorescent lights were used during the measurements.

Another similar work was published by Odioso *et al.*[5]. These authors studied 180 American participants, ranging from 13 to 64 years of age. Tooth colour (L*a*b*) was measured on the maxillary central incisors using a spectrophotometer. Their mean results were L*= 69.3, a*= 5.4 and b*= 18.7. The study did not take into account any gender or age distinctions. Furthermore, the authors concluded that after adjusting for other explanatory variables (age, gender, coffee/tea consumption and dental care) all significantly affected yellowing (b*) and lightness (L*)[5]. These other variables were not taken into account in this work, but they may be relevant for future studies.

Following the manufacturer's indications for data collection, the spectrophotometer used in the present study was subjected to a reliability test to guarantee the validity and accuracy of the measurements. Only one person was responsible for data collection, to minimise the inherent variability that arises when data are collected by several different people. Many authors who have recently studied different features related to tooth colour used the Easyshade compact (Vita-Zahnfabrik) spectrophotometer to record colour coordinates[29–31]. The position of the probe tip of the spectrophotometer on the tooth surface is important when obtaining colour coordinates. As no positioners were used for participants, it is not possible to guarantee that the probe tip will always be repositioned in exactly the same place.

These devices (spectrophotometers) are designed for smooth surfaces, essential for reliable measurements to be obtained. In this sense, their use in dentistry is hindered by the convex surface of teeth, which complicates the correct placement of the spectrophotometer's probe tip. The probe tip of the Easyshade compact spectrophotometer captures approximately 25% of the colour reflected back from the tooth surface measured[20]. Therefore, the middle area was the area most representative of a tooth's colour, whereas the translucency of enamel at the incisal site was affected by background and the cervical site was affected by pink gingival tissue[17,21,22,24,32,33]. According to Amaechi *et al.*, the highest L* values can be found in the middle third of the tooth[34].

The upper central incisor has been frequently used to assess tooth colour, as representative of the natural tooth colour of a person[9,17,20,23,35–37]. This is why it was used in the present work. Other authors used different teeth, such as Eiffler *et al.*[21] who measured all maxillary anterior teeth and first bicuspids, as well as mandibular canines and central incisors. Cocking *et al.*[22] also included upper bicuspids, all upper maxillary front teeth and the canine and central incisors of the mandible in their work. Generally speaking, maxillary anterior teeth are slightly yellower than mandibular anterior teeth[17] and the maxillary central incisor has a greater amount of lightness than the upper lateral tooth and the upper canine[9,11,17,38]. According to Dozić *et al.*[25] there is a colour relationship between the maxillary incisors and canines, which is stronger between the cervical segments than between the middle and incisal segments.

In the present study, all participants were White Spanish men and women and hence the results cannot be extended to other races but they can be compared with those of other similar studies. Jahangiri *et al.*[16] studied the relationship between tooth shade and skin colour in an observational study. No interactions were found among age, skin colour and tooth shade, or gender, skin colour and tooth shade; however, age was associated with tooth shade. Another study revealed a significant relationship between tooth shade and skin colour, with a total correlation factor of 51.6% ($P < 0.01$)[39]. Regarding significant differences between men and women, not all authors are in agreement. Men have higher C* and less lightness or L* in tooth colour than women[5,37,40]. In 1987, Goodking also reported that women's teeth are less yellow, lighter and have lower C* shades[17]. In the present study, the degree of correlation between all the colour and age coordinates was higher in men than in women and there were differences in the average values of the colour coordinates (*Tables 2 and 3*). These differences in men and women are supported by the results of this work. Odioso *et al.*[5] attempted to quantify this difference between gender and stated that the average value of L* for upper central incisors was 3.7 units lower in men than in women. In the present work, the difference in the average value of L* between men and women was slightly lower in men (2.53 units). It has also been reported that as age increases, the b* variable increases faster in men than in women[5]. Bearing in mind the results of this work, the greatest differences in average values between men and women are found in the C* and b* coordinates, being 3.16 and 3.11 units higher in men, respectively. Analysis of the data shown in *Figures 1–3* reveals that the 95% confidence interval changes homogeneously in men and women with increasing age.

Conversely, the results of other studies showed no significant differences in tooth colour between men and women[41,42]. Hasegawa *et al.*[38] failed to find any statistically significant differences between genders in

L*, a* and b*, on a sample of 87 Japanese individuals. Moreover, Zhu *et al.*[19] did not find any statistically significant differences between Chinese men and women.

There is more agreement among authors[6,9,11,16] that teeth become darker and yellower as the population grows older. One of the few studies that failed to find significant differences in tooth colour between the 50–59 years and the 70–29 years age-groups was that of Eiffler in 2010[21]. The effect of age on tooth colour can be attributed to the following factors: the pulp chamber retracts, leaving secondary dentin in its place[22,38,43]; and secondary dentine hardens and becomes less permeable. One hypothesis states that pigments and amorphous organic and inorganic ions penetrate the enamel and settle on the amelocemental junction of the dentin structure[43]. Thus, dentinal chroma becomes more saturated and both tooth value and enamel thickness decrease. As a result of normal tooth function, dentinal colour becomes more dominant in tooth colour. With age, the tooth surface gradually wears, becoming smoother, regardless of brightness[44]. All teeth become darker over time, although this might also be determined genetically[43].

Zhu *et al.*[19] found that L* and a*, but not b*, were negatively related to age. In agreement, in 2000 Hasegawa and Ikeda[43] reported that there is a negative correlation between age and L*, and a positive relationship between age and b*. The results of this work confirm what was stated above: as age increases, there is significant inverse correlation ($P < 0.001$) in the L* and h* coordinates and a significant positive correlation ($P < 0.001$) in the C*, a* and b* coordinates (*Table 2*).

Unfortunately, only limited scientific information is available concerning the quantification of changes occurring in each colour coordinate each year and the relationship between tooth shade, skin and gingival colour. Odioso *et al.*[5] reported that for each year of life, the range of yellow increased by 0.10 b* units and lightness decreased by 0.22 L* units[5]. According to the findings of the present work on a Spanish population, and without considering behavioural variables, some differences in the quantification of colour change for each year of age can be noted. The L*, C* and h* variables change, on average, by 0.60 units/year, and the a* and b* variables change, on average, by 0.26 units and 0.56 units, respectively. That is, the change in the b* variable each year is approximately double that of the a* variable.

In 2008, Gozalo Díaz *et al.*[37] formulated the hypothesis that participants' age and gender can be used to estimate the CIELAB value of their maxillary central incisors. This hypothesis is very useful for tooth colour determination in completely edentulous patients. Age and gender were found to be statistically significant factors in the prediction of the three colour parameters for the maxillary incisors; the linear regression model yielded variability rates of 36% for L*, 16% for a* and 21% for b*[37]. These results agree with our own, because the highest correlation was found in the L* variable ($r = -0.674$). The significant correlation between age and all the colour coordinates is apparent in both men and in women.

Hasegawa *et al.*[9] and Schawacher *et al.*[33] underscored the importance of having a large database of the colours of natural teeth '*in vivo*' regarding age and gender groups in which the whole colour spectrum of natural teeth is included. The authors of the present work are in complete agreement with this idea. For this purpose, studies using spectrophotometry and a larger sample, carried out in different countries and with people of different races, are needed.

This preliminary transversal work aims at exploring the correlation between the colour coordinates associated with aging, and offers some working hypotheses for future work. In order to identify most important data, it would be advisable to carry out longitudinal studies and spectral measurements on representative samples at different temporal moments, as well as to include behavioural variables associated with participants.

CONCLUSIONS

Taking into account the limitations of this study, it can be stated that the strongest correlation is found between age and the L* variable, then between age and the h* variable (both inverse relationships) and then between age and a*, C* and b* (direct relationships). In addition, the colour coordinates (L*, C* and h*) change in a similar way, on average by 0.60 units/year, in natural tooth colour.

Acknowledgment

The authors acknowledge the assistance of the statistician, Dra. Carmen Bravo.

Competing interest statement

None declared

REFERENCES

1. Morley J. The role of cosmetic dentistry in restoring a youthful appearance. *J Am Dent Assoc* 1999 130: 1166–1172.
2. Sproull RC, Part III. Color control. *J Prosthet Dent* 1974 31: 146–155.
3. Joiner A. Tooth colour: a review of the literature. *J Dent* 2004 32(Suppl 1): 3–12, Review.

4. Qualtrough AJ, Burke FJ. A look at dental esthetics. Quintessence International. *Quintessence Int* 1994 25: 7–14.
5. Odioso LL, Gibb RD, Gerlach RW. Impact of demographic behavioral, and dental care utilization parameters on tooth color and personal satisfaction. *Compend Contin Educ Dent* 2000 29(suppl): S35–S41.
6. Xiao J, Zhou XD, Zhu WC *et al.* The prevalence of tooth discolouration and the shelf-satisfaction with tooth color in a chinese urban population. *J Oral Rehabil* 2007 34: 351–360.
7. Al-Zarea BK. Satisfaction with appearance and the desired treatment to improve aesthetics. *Int J Dent* 2013 2013: 912368.
8. Kershaw S, Newton JT, Williams DM. The influence of tooth colour on the perceptions of personal characteristics among female dental patients: comparisons of unmodified, decayed and 'whitened' teeth. *Br Dent J* 2008 204: E9; discussion 256-7.
9. Hasegawa A, Motonomi A. Color of natural tooth crown in Japanese people. *Color Res Appl* 2000 25: 43–48.
10. Paul S, Peter A, Pietrobon N *et al.* Visual and spectrophotometric shade analysis of human teeth. *J Dent Res* 2002 81: 578–582.
11. Zhao Y, Zhu J. In vivo color measurement of 410 maxillary anterior teeth. *Chin J Dent Res* 1998 1: 49–51.
12. Macentee M, Lakowski R. Instrumental colour measurement of vital and extracted human teeth. *J Oral Rehabil* 1981 35: 203–208.
13. Russell MD, Gulfraz M, Moss BW. In vivo measurement of colour changes in natural teeth. *J Oral Rehabil* 2000 27: 786–792.
14. Tung FF, Goldstein GR, Jang S *et al.* The repeatability of an intraoral dental colorimeter. *J Prosthet Dent* 2002 88: 585–590.
15. CIE (Commission Internationale de l'Éclairage) Annuaire, Roster, Register, AnnexeauBulletinCIE (Paris: Bureau Central de la CIE). (PROCLUS, patrimonio Conicet), 1976.
16. Jahangiri L, Reinhardt SB, Mehra RV *et al.* Relationship between tooth shade value and skin color: an observational study. *J Prosthet Dent* 2002 87: 149–152.
17. Goodkind RJ, Schwabacher WB. Use of a fiber-optic colorimeter for in vivo color measurements of 2830 anterior teeth. *J Prosthet Dent* 1987 58: 535–542.
18. Gómez-Polo C, Gómez-Polo M, Celemín-Viñuela A *et al.* A clinical study relating CIELCH coordinates to the color dimensions of the 3D-Master System in a Spanish population. *J Prosthet Dent* 2015 113: 185–190.
19. Zhu H, Lei Y, Liao N. Color measurements of 1944 anterior teeth of people in southwest of China discreption. *Zhonghua-Kou Qiang Yi XueZaZhi* 2001 36: 285–288.
20. Yuan JC, Brewer JD, Monaco EA Jr *et al.* Defining a natural tooth color space based on a 3-dimensional shade system. *J Prosthet Dent* 2007 98: 110–119.
21. Eiffler C, Cevirgen E, Helling S *et al.* Differences in lighness, chroma, and hue in the anterior teeth of quinquagenarians and septuagenarians. *Clin Oral Investig* 2010 14: 587–591.
22. Cocking C, Cevirgen E, Helling S *et al.* Colour compatibility between teeth and dental shade guides in Quinquagenarians and Septuagenarians. *J Oral Rehabil* 2009 36: 848–855.
23. Rubiño M, García JA, Jimenez del Barco L *et al.* Colour measurement of human teeth and evaluation of a colourguide. *Color Res Appl* 1994 19: 19–22.
24. Hassel AJ, Doz P, Nitschke I *et al.* Comparing L*a*b* color coordinates for natural teeth shades and corresponding shade tabs using a spectrophotometer. *Int J Prosthodont* 2009 22: 72–74.
25. Dozić A, Kleverlaan CJ, Aartman IH *et al.* Relations in color among maxillary incisors and canines. *Dent Mater* 2005 21: 187–191.
26. Ge QM, Zhang FQ. Comparison of clinically used shade guide systems with color range of natural teeth. *Zhonghua Kou Qiang Yi Xue Za Zhi.* 2008 43: 422–425.
27. Schmitter M, Mussotter K, Hassel AJ. Interexaminer reliability in the clinical measurement of L*C*h* values using a laminar spectrophotometer. *Int J Prosthodont* 2008 21: 422–424.
28. Baltzer A, Kaufmann-Jinoian V. The determination of the tooth colors. Special reprint. *Quintessenz Zahntechnik* 2004 30: 726–740.
29. Niu E, Agustin M, Douglas RD. Color match of machinable lithium disilicate ceramics: Effects of foundation restoration. *J Prosthet Dent* 2013 110: 501–509.
30. Gómez-Polo C, Gómez-Polo M, Celemín-Viñuela A *et al.* Differences between the human eye and the spectrophotometer in the shade matching of tooth colour. *J Dent* 2014 42: 742–745.
31. Zenthöfer A, Cabrera T, Corcodel N *et al.* Comparison of the easyshade compact and advance in vitro and in vivo. *Clin Oral Investig* 2014 18: 1473–1479.
32. O'Brien WJ, Hemmendinger H, Boenke KM. Color distribution of three regions of extracted human teeth. *Dental Mater* 1997 13: 179–185.
33. Schwabacher WB, Goodkind RJ. Three-dimensional color coordinates of natural teeth compared with three shade guides. *J Prosthet Dent* 1990 64: 425–431.
34. Amaechi BT, Higham SM. Quantitative light-induced fluorescence: a potential tool for general dental assessment. *J Biomed Opt* 2002 7: 7–13.
35. Clark EB. An analisys of tooth color. *J Am Dent Assoc* 1931 18: 2093–2103.
36. Odaira C, Iskibashi K, Nagai S. Comparison of color gradation for natural dental incisors and corresponding shade tabs (abstract). *J Dent Res* 2003 82: B-249..
37. Gozalo-Diaz D, Johnston WM, Wee AG. Estimating the color of maxillary central incisors based on age and gender. *J Prosthet Dent* 2008 100: 93–98.
38. Hasegawa A, Ikeda I, Kawaguchi S. Color and translucency of in vivo natural central incisors. *J Prosthet Dent* 2000 83: 418–423.
39. Nourbakhsh M, Mousavinejad N, Adli AR *et al.* Relationship between natural tooth shade and skin colour. *Eur J Prosthodont Restor Dent* 2013 21: 50–52.
40. Esan TA, Olusile AO, Akeredolu PA. Factors influencing tooth shade selection for completely edentulous patients. *J Contemp Dent Pract* 2006 1: 80–87.
41. Douglas RD, Brewer JD. Acceptability of shade differences in metal ceramic crowns. *J Prosthet Dent* 1998 79: 254–260.
42. Alghazali N, Burnside G, Moallem M *et al.* Assessment of perceptibility and acceptability of color difference of denture teeth. *J Dent* 2012 40(Suppl 1): e10–e17.
43. Morley J. The esthetics of anterior tooth aging. *Curr Opin Cosmet Dent* 1997 4: 35–39.
44. Winter R. Visualizing the natural dentition. *J Esthet Dent* 1993 5: 103–117.

Correspondence to:
Cristina Gómez Polo,
Department of Dentistry,
School of Medicine,
Campus Miguel de Unamuno s/n 37007 Salamanca,
University of Salamanca,
Salamanca, Spain.
E-mails: crisgodent@usal.es /crisgodent@hotmail.com

