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TWO DIFFERENT METHODS FOR ASSESSING TOOTH COLOR – IN VITRO STUDY

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À minha mãe, que acompanhou sempre o meu percurso
com especial atenção e que colhe grande prazer
de todas as minhas conquistas e sucessos.

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ABSTRACT

Purpose: To determine and compare the L*a*b* values in color measurement of Vitapan Classical and Vitapan 3D Master shade guides, using two different digital methods.

Materials and Methods: SpectroShade and eLAB were tested. One operator performed 34 measurements per tab of three different batches of each shade guide. Intraclass correlation coefficient (ICC) between batches for each method was calculated. Values <0.5, between 0.5-0.75, 0.75-0.9, and >0.90 are indicative of poor, moderate, good, and excellent reliability. Results were given as mean and standard deviation (SD) of the L*a*b* values and the respective color differences according to the CIEDE 2000 formula (ΔE_{00}) per tab, per method, then analysed with an independent student t-test (α=0.05).

Results: ICC values between batches were considered excellent for all L*a*b* parameters except for the a* component in eLAB, which was considered good. There were statistically significant differences between the two methods for all L*a*b* values, except for: L* for D4, 2M2, 3R1.5, 3M2, 3R2.5, 4L1.5, 4L2.5; a* for 2M2, 3R1.5; b* for D4, 3R1.5, 3M2, 3R2.5. The total mean of ΔE_{00} intra-device for the SS was 0.5±0.6 for VC and 0.5±0.8 for VM, and for the eLAB was 1.1±0.8 for VC and 1.1±0.9 for VM. The total mean of ΔE_{00} inter-device was 4.9±1.7 for VC and 5.0±1.7 for VM.

Conclusion: Both methods presented high ICC values, which suggests a good internal consistency. However, discrepancies between methods were observed, higher for the a* component. Additional studies are needed to evaluate the clinical effect of this variability.

Keywords: tooth color, eLAB, SpectroShade, spectrophotometry, photography

RESUMO

A cor em Medicina Dentária é uma área relevante para a aplicação clínica, investigação e educação. A avaliação da cor dentária constitui um passo importante na componente restauradora da medicina dentária e uma correspondência bem-sucedida requer uma seleção de cor e replicação apropriadas.

Atualmente, a escolha de cor em Medicina Dentária ainda é considerada um processo subjetivo, dependente de 3 fatores principais: a fonte de luz, o objeto e o observador, sendo que existem 2 métodos principais para avaliar a cor: visual com auxílio de escalas e instrumental com o auxílio de aparelhos. Para reduzir esta subjetividade, os fabricantes têm, ao longo dos últimos anos, lançado para o mercado novos dispositivos que pretendem auxiliar os clínicos na escolha da cor, através de métodos colorimétricos e/ou espectrofotométricos. As técnicas de seleção de cor digitais tornaram-se métodos essenciais para os clínicos, uma vez que a fotografia e os espectrofotómetros são métodos simples e facilmente obtidos.

De forma a uniformizar a medição da cor, a *Commission Internationale de l'Eclairage* (CIE, Comissão Internacional de Iluminação) adotou o espaço de cor CIELAB, que é o mais comummente utilizado em Medicina Dentária o qual se organiza em 3 coordenadas: L* (luminosidade); a* (eixo vermelho-verde) e b* (eixo amarelo-azul). Duas medições do mesmo objeto podem ser comparadas com a sua diferença de cor (ΔE_{00} – fórmula CIEDE2000), a qual pode ser definida como percetível e/ou aceitável para o olho humano. A percetibilidade refere-se à deteção da diferença de cor entre o dente e uma restauração adjacente, enquanto a aceitabilidade refere-se à aceitação da cor dessa restauração. O limite de percetibilidade do ΔE_{00} é de 0,8 e o limite de aceitabilidade é de 1,8.

Embora a seleção de cor através da utilização de escalas visuais ainda seja a técnica mais utilizada, dada à facilidade de utilização e baixo custo, esta está associada a diversas limitações, tais como, a subjetividade entre operadores, a influência da luz ou do fundo e as amostras das guias de cor não estarem uniformemente espaçadas e organizadas. Assim, tem ocorrido um aumento exponencial da utilização de métodos instrumentais.

No caso de métodos visuais com a utilização de escalas de cor, existem duas escalas mais utilizadas a nível mundial a escala *VITA Classical* (VC) e a *VITA 3D Master* (VM). A VC consiste em 16 guias de cor e envolve 4 grupos: A, B, C e D, que representam matizes diferentes. Cada grupo possui uma variedade de cores, que representa um aumento na saturação do pigmento, concomitante com uma diminuição na luminosidade

para cada guia dentro desse grupo. No entanto, o número de cores é insuficiente e as diferenças de cor entre guias não são uniformes e sistemáticas.

A VM apresenta uma faixa de cores mais ampla e uniforme, com uma melhor distribuição de cores e melhor repetibilidade na medição de cor, quando comparada com outras escalas de cor. Consiste em 29 guias de cor, divididas em 5 grupos de luminosidade, do 1 ao 5.

Uma avaliação da cor dentária padronizada é possível com a utilização de dispositivos digitais como espectrofotómetros e máquinas fotográficas. Embora os métodos instrumentais tenham ganho popularidade e tenham demonstrado uma boa reprodutibilidade, existem discrepâncias entre aparelhos diferentes e estes requerem uma tecnologia específica e dispendiosa, que nem sempre está disponível para os clínicos.

O *SpectroShade Micro* é um espectrofotómetro dentário que tem uma melhor precisão, relativamente a outros espectrofotómetros. Devido à sua precisão e confiabilidade, pensa-se que seja o *standard* clínico para avaliação da cor. Além disso, a utilização de um espectrofotómetro em combinação com uma escala de cor pode providenciar melhores resultados que a avaliação visual isoladamente.

No entanto, as máquinas fotográficas têm sido utilizadas para quantificação da cor, para melhorar a comunicação com o técnico de prótese e para capturar a cor policromática, a morfologia, a textura da superfície, a translucidez, a distribuição da cor e o brilho do dente e os detalhes do tecido circundante.

De forma a uniformizar a fotografia digital, são necessários a calibração e o ajuste de cor. Um cartão de referência de balanço de brancos, com coordenadas de cor conhecidas, tem sido recomendado para melhorar a exatidão na aquisição de imagens de cor na fotografia dentária digital.

Devido à sua objetividade, lógica e capacidade de expressar diferenças de cor numericamente, o CIELAB constitui o alicerce para o sistema eLAB, com o objetivo de substituir a utilização das escalas de cor. O sistema eLAB centra-se num protocolo padronizado de fotografia dentária. Este sistema utiliza a polarização cruzada, que elimina o brilho e os reflexos especulares, um cartão de referência cinzento e configurações padrão para a máquina fotográfica. A fotografia com polarização cruzada melhora a visualização da tonalidade da dentina e das características do esmalte, providenciando um mapa cromático com contraste naturalmente melhorado.

O protocolo eLAB não foi projetado para fornecer um mapa de camadas completo ou para substituir a perícia e experiência de um ceramista bem treinado. Em vez disso, tem a intenção de complementar estes atributos e de guiar o ceramista para uma correspondência de cor que se situe dentro do limite de aceitabilidade clínica.

No presente estudo *in vitro* foi utilizado um modelo de forma a simular as condições de luz da cavidade oral, para avaliar dois métodos diferentes de avaliação da cor dentária, o SpectroShade Micro e o método fotográfico eLAB.

O objetivo deste estudo é determinar os valores L*a*b* na medição da cor de cada guia das escalas *VITA Classical* e *Vitapan 3D Master*, utilizando dois métodos diferentes. A hipótese nula é que não existem diferenças estatisticamente significativas entre os valore L*a*b* das duas escalas determinados com cada método.

Um operador realizou 34 medições por cada guia, de três lotes diferentes de duas escalas de cor, *VITA Classical* e *VITA 3D Master*. No total, foram realizadas 102 medições para cada guia por cada método. Para o SpectroShade Micro foram utilizados métodos previamente estabelecidos e para o eLAB, utilizou-se a uma câmara escura previamente descrita e as fotografias adquiridas com as configurações pré-definidas, o cartão de referência e o filtro de polarização cruzada. As fotografias foram posteriormente analisadas no software Adobe Lightroom®.

Foi calculado o coeficiente de correlação intraclasse (ICC) entre lotes para cada método, com um intervalo de confiança de 95%, considerando a seguinte interpretação: reprodutibilidade excelente (> 0,9), boa (0,75-0,9), moderada (0,5-0,75) e reduzida (< 0,5).

Os resultados foram apresentados na forma de média e desvio-padrão dos valores L*a*b* e as respetivas diferenças de cor, de acordo com a fórmula CIEDE2000 (ΔE_{00}) para cada guia de cor nos dois métodos, e depois analisados com teste *t* de amostras independentes.

Um total de 1632 e 2958 medições para VC e VM, respetivamente, foram executadas por método. Verificaram-se diferenças estatisticamente significativas entre os dois métodos para todos os valores L*a*b*, com a exceção de: L* para D4, 2M2, 3R1.5, 3M2, 3R2.5, 4L1.5 e 4L2.5; a* para 2M2 e 3R1.5; e b* para D4, 3R1.5, 3M2 e 3R2.5. Ao avaliar a mesma escala de cor, os valores ΔE_{00} entre os aparelhos ficaram acima do limite de aceitabilidade ($\Delta E_{00} \geq 1.8$) para todas as guias de cor. A média global do ΔE_{00} entre dispositivos foi 4,9±1,7 para a VC e 5,0±1,7 para a VM.

Os resultados dos três lotes foram analisados em conjunto e apresentaram valores de ICC elevados, sendo que o menor valor para o eLAB foi 86%, classificado como bom, e para o SS foi 97%, classificado como excelente.

Ambos os métodos apresentaram ICC elevados, o que sugere uma boa consistência interna. No entanto, foram observadas discrepâncias entre os métodos nas diferentes guias de cor, maiores para a componente a*. São necessários estudos adicionais de forma a avaliar o efeito clínico desta variabilidade.

Palavras-chave: cor dentária, eLAB, SpectroShade, espectrofotometria, fotografia

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LIST OF ABBREVIATIONS

ICC – Intraclass Correlation Coefficient

SD – Standard Deviation

VC – VITA Classical

VM – VITA 3D Master

SS – SpectroShade

CI – Confidence Interval

LED – Light Emitting Diode

EOS – Electro-Optical System

DSLR – Digital Single Lens Reflex

INTRODUCTION

Color in dentistry is an ever-expanding field that is equally relevant for clinical application, research, and education. [1–4] Therefore, tooth color determination is important to both dental professionals and patients. [5,6]

Tooth color visual determination in dentistry is a subjective process, relying on 3 main factors: light source, object, and observer. [6,7] To standardize color determination, the Commission Internationale de l'Eclairage (CIE, International Commission of Illumination) adopted the CIELAB color space [8,9], commonly used in dentistry [4], which describes three dimensions of color, lightness, chroma, and hue. [5,10]

The CIELAB system consists of 3 coordinates: L* (luminosity) [6]; a* (red-green axis) and b* (yellow-blue axis). [9,10] Two measurements of the same object can be compared to assess color differences (ΔE), which can be defined as perceptible and/or acceptable to human observers. Perceptibility refers to the detection of color difference between a tooth and an adjacent restoration, whereas acceptability refers to the acceptance of the color of that restoration. [1,7,11]

Various color difference formulas have been used over the years in dentistry. [1] Improvements in color difference equations resulted in CIEDE2000 (ΔE_{00}), a more reliable formula. [8,10] This equation is still based on CIELAB color space, and the definition of its thresholds is dependent on its application. [8] The used thresholds for perceptibility and acceptability in dentistry were 0.8 and 1.8, respectively. [1]

Two main methods exist to assess color in dentistry: visual and digital. [7,12,13] Visual selection by using shade guides is the most common [9], but also highly subjective. [7] Its limitations include the subjective color selection between different operators, influence by the surrounding ambient, and the tabs not being uniformly distributed. In consequence, digital instruments to assess tooth color are increasingly being used. [5]

Visual selection is performed with shade guides. The two most common shade guides are the VITA Classical (VC) and the VITA 3D Master (VM). [5,10] The VITA Classical shade guide, consisting of 16 tabs, which involves four groups: A, B, C, and D, representing reddish, yellowish, reddish-grey, and yellowish-grey teeth respectively. Each group has a small range within, representing a simultaneous increase in pigment saturation and decrease in lightness per tab of the same group. However, the increments of color gradients are arbitrary making it challenging to accurately reproduce the shade code of the tab. [2] Its weaknesses include the inadequate range of shades and the unsystematic color differences. [6]

The VITA 3D Master Toothguide was designed to have a broader and more uniform color range, better color distribution, and improved repeatability of measurements as compared to other shade guides. (6) It consists of 29 tabs that are ordered around the parameters of lightness, chroma, and hue (5), divided into five groups of value, from 1 to 5. (9,14)

Instrumental methods such as spectrophotometers gained popularity. (7) However, they have poor inter-device reliability and require specific and expensive technology, not always available to the clinician. (7,15,16)

SpectroShade Micro (MHT Medical High Technologies, Bologna, Italy) is an imaging dental spectrophotometer that uses a digital camera/LED spectrophotometer combination. It has better accuracy than similar devices, such as EasyShade. (14,16)

Spectrophotometric assessment of tooth color showed to be more accurate than visual assessment. (4,13)

Digital cameras have been used for tooth color quantification, to improve color communication (5), and to capture teeth characteristics and detail of the surrounding tissue. (7,17) To enhance digital photography, calibration and color adjustment are required. (18)

The eLAB system has its foundation in CIELAB and it is centered around a standardized protocol for dental photography. (8) This system uses cross-polarization, which eliminates brightness and specular reflections (8,9), a grey reference card, and standard camera settings. (8) Once the cross-polarized image has been taken, it can be imported into the eLAB_prime application for convenient automatic calibration. (8)

The eLAB protocol is intended to complement the skills and experience and to guide the ceramist towards a shade match that lies within the threshold of clinical acceptability. (8)

Thus, in this study an in vitro model previously described and published was used to simulate the light conditions of the oral cavity, to compare two different methods for assessing tooth color, SpectroShade Micro and the eLab photographic method.

The objective of this study is to determine and compare L*a*b* values of each tab of Vitapan Classical and Vitapan 3D Master shade guide using two different methods. The null hypothesis tested in this study was that there are no statistically significant differences between the determined L*a*b* values of the two shade guides tabs with each method.

MATERIALS AND METHODS

The present study evaluated two methods for assessing tooth color. The SpectroShade Micro (SN: HDL3973, MHT Spa, Italy) and the eLab photographic protocol.

In the present study, 34 consecutive measurements of each tab of the 2 shade guides in 3 different batches in each method were assessed: Vitapan Classical (VC) (VITA Zahnfabrik) with 16 color tabs and Vitapan 3D Master (VM) (VITA Zahnfabrik) with 29 color tabs (VITA Bleached Shade Guide color guides included). Three different batches for VC (B027C; B027CV1; B27C), and for VM (B360ASP; B260ASP; B360APOR), were used.

According to previously established methods [(16)], the manufacturer's instructions were followed, and the equipment calibrated using the white and green tiles, before the measurement of each tab. The optical piece was placed at a 90° with each tab to be measured, leaning against the gingival matrix.

A preestablished method was used with the assistance of a dark chamber. [(15,16,19)] Using the eLab protocol, the photographs were performed with a Reflex Canon EOS 1300D camera, a 100mm macro F2.8L lens, a Canon Macro Twin Lite MT-26EX-RT flash, a cross polarizer filter (Polar_eyes®), and eLAB_prime white balance card (Emulation, Freiburg, Germany).

The photographs were taken and analysed according to the manufacturer's instructions. Posteriorly, each photograph was imported to the Adobe Lightroom® software, in RAW format. After importation, it is important to choose the correct DSLR camera profile from the Lens Corrections menu in the Develop mode (Figure 1). Next, the White Balance tool is selected (pipette) and by clicking on any of the four grey segments images, the white balance correction is performed (Figure 2). To carry out exposure balance, the operator selected the three zeros next to the exposure slider, with the cursor becoming a magnifying glass when moved over the four grey segments and operating the up/down arrow on the keyboard adjusts image exposure. This is carried out until the known luminosity value (L*79) of the grey reference card has been replicated (Figure 3). [(20)]

Figure 1 Selection of the correct DSLR camera profile

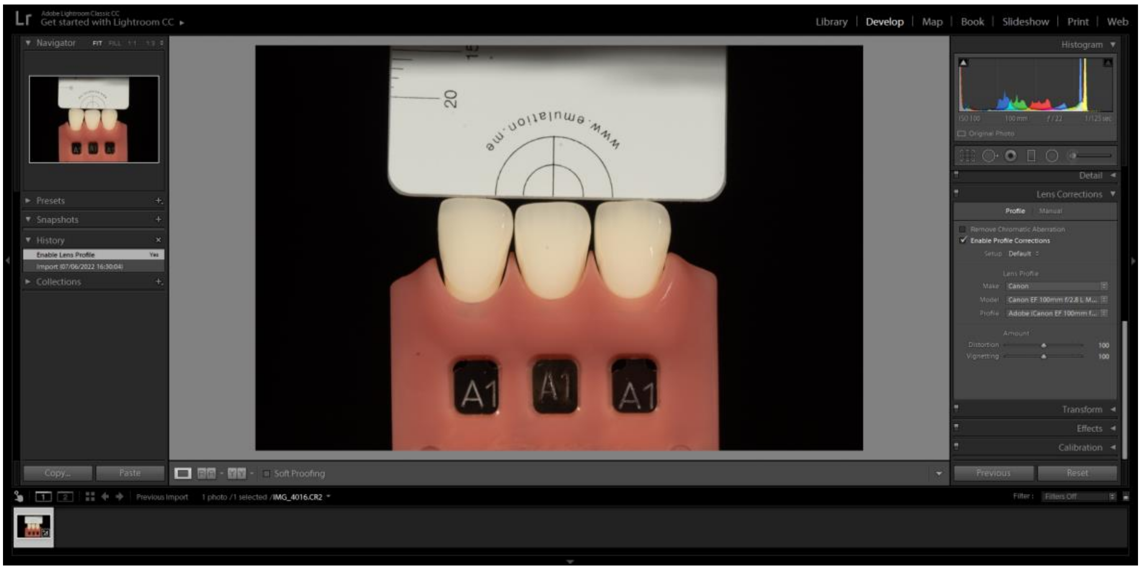


Figure 2 White Balance Correction

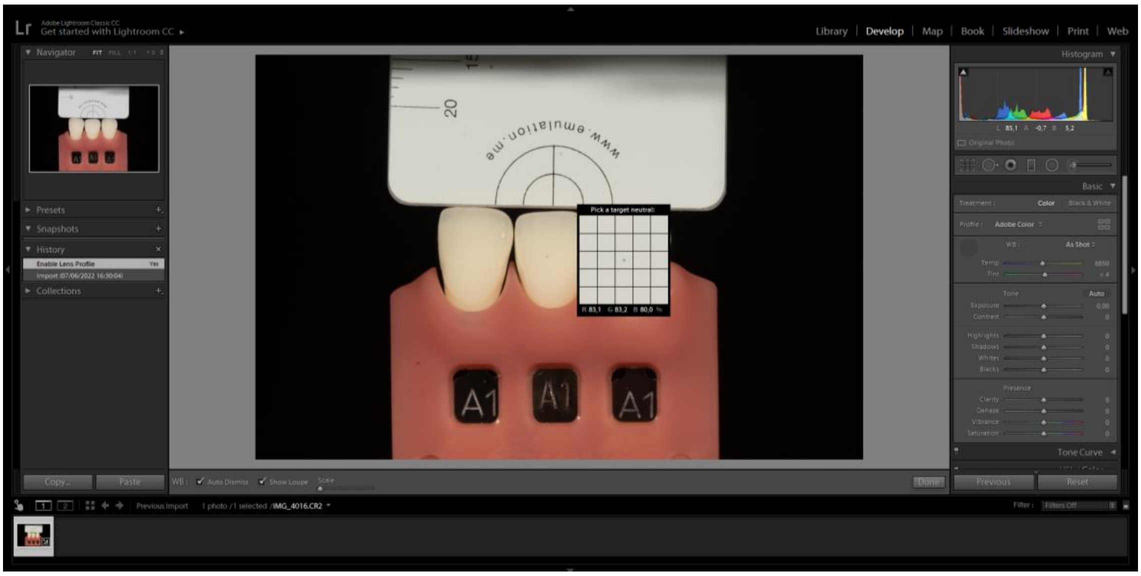
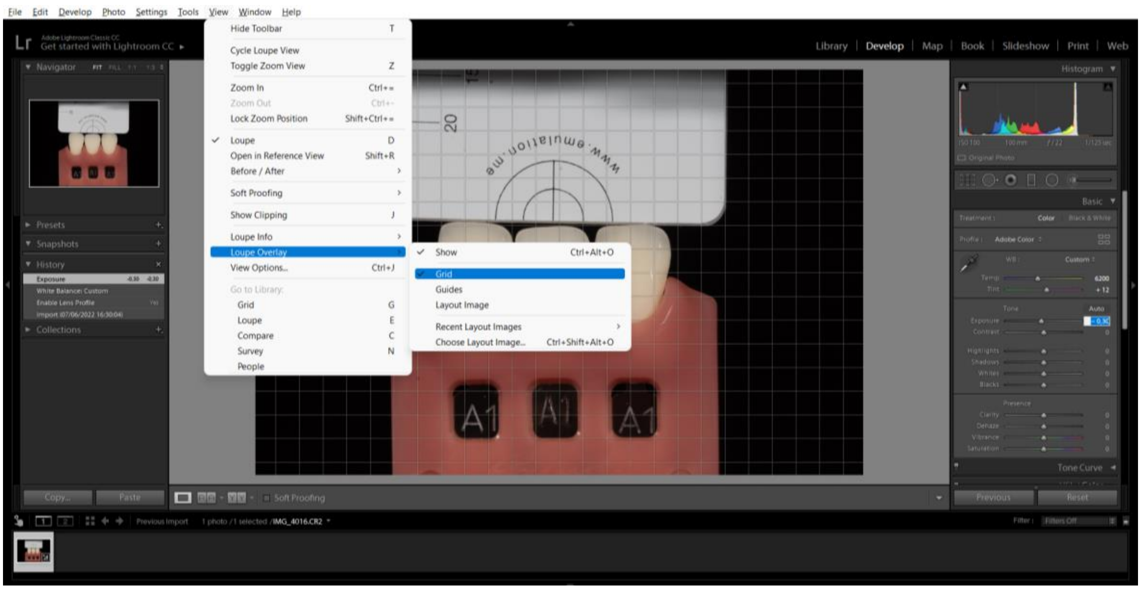


Figure 3 Exposure Correction

For each photograph and each tab, 4 corresponding centre points were obtained, through a pre-established grid, and the L*, a*, b* values were measured with Classic Color Meter® software. The grid was obtained in the Adobe Lightroom® software (View > Loupe Overlay > Grid > Size 40) (Figure 4).

Figure 4 Measurement Grid



The sample size was calculated based on the color difference (ΔE_{00} – a primary outcome) recorded in a previously performed study [16] (https://sample-size.net/sample-size-means/). The sample size was calculated based on the ΔE_{00} difference of 0.5 with a standard deviation of 0.5 for VC and VM. [16] Considering a T statistic and non-centrality parameter with a significance level of 5% and a power of 80%, a minimum of 34 measurements per tab in each shade guide would be required. In this study, a total of 102 measurements was performed per tab considering 3 shade guides per group.

For each shade guide, the agreement and reproducibility between different batches was evaluated by the Intraclass Correlation Coefficient (ICC) with a confidence interval of 95% (CI 95%), considering the following interpretation of ICC: excellent (>0.9), good (0.75-0.9), moderate (0.5-0.75) and poor (<0.5) reliability.[21] To consider variability between batches of the same guide, data from the three different batches of each shade guide were analysed together, if the obtained ICC was higher than 80%. [16]

The differences in color for each tab (intra-method, inter-method global, and for each component, ΔL^*, Δa^*, Δb^*) were determined by ΔE_{00}, calculated with the CIEDE2000 formula. [1] Color difference perception was evaluated with two major thresholds: perceptibility threshold (PT) considered as $\Delta E_{00}=0.8$ and acceptability threshold (AT) considered as $\Delta E_{00}=1.8$.[1,22]

The results were presented in the form of mean and standard deviation (σ) for each shade tab of both guides with both methods and ΔE_{00} between them. The results were analysed with an independent t-test, with a significance level of 0.05.

Data analysis and results were obtained using statistical pack SPSS (IBM Statistics v.25, Inc, Chicago, IL, USA).

RESULTS

A total of 1,632 and 2,958 measurements for VC and VM, respectively, were performed per method.

The ICC between each component measurement (L*, a*, b*) and the shade guide Vita Classical and Vita 3D Master, in each method, are depicted in Table 1 (SS) and Table 2 (eLAB). The data from the three different batches were analysed together, resulting in a total of 102 measurements for each tab, and presented a high ICC agreement, 86% being the lowest value for eLAB, classified as good, and 97% for SS, classified as excellent. [21]

Table 1: Mean and confidence intervals 95% of Intraclass Correlation Coefficient (ICC) between the three batches for each component L*, a*, and b* of each shade guide, for SpectroShade.

	VC		**VM**	
	ICC	CI 95%	ICC	CI 95%
L*	0.984	[0.982-0.987]	0.990	[0.989-0.991]
a*	0.972	[0.968-0.976]	0.991	[0.990-0.992]
b*	0.983	[0.980-0.985]	0.993	[0.992-0.993]

Table 2: Mean and confidence intervals 95% of Intraclass Correlation Coefficient (ICC) between the three batches for each component L*, a*, and b* of each shade guide, for eLAB.

	VC		**VM**	
	ICC	CI 95%	ICC	CI 95%
L*	0.968	[0.964-0.973]	0.970	[0.967-0.973]
a*	0.970	[0.965-0.974]	0.862	[0.848-0.875]
b*	0.982	[0.979-0.984]	0.988	[0.987-0.990]

The mean and standard deviation of L*a*b* and ΔE_{00} in the two methods with respective statistical significances, are presented in Table 3 (VC) and Table 4 (VM). The total mean of ΔE_{00} for eLAB was 1.1±0.8 for VC and 1.1±0.9 for VM; for SS was 0.5±0.6 for VC and 0.5±0.8 for VM. The ΔE_{00} inter-device was 4.9±1.7 for VC and 5.0±1.7 for VM, with detected statistical differences between devices above the AT considered for all shade tabs for VC and VM. There were statistically significant differences between the two methods for all L*a*b* values, with the exception of: L* for D4, 2M2, 3R1.5, 3M2, 3R2.5, 4L1.5, and 4L2.5; a* for 2M2, and 3R1.5; and b* for D4, 3R1.5, 3M2, and 3R2.5.

Table 3: eLAB and SpectroShade (SS) L*a*b* mean and standard deviation (SD) values comparison, intra-device (ΔE00 eLAB and ΔE00 SS), and inter-device ΔE00 for each tab of Vita Classical (VC). Results in bold are statistically significant.

VC		SS	ΔE_{00} SS	eLAB	ΔE_{00} eLAB	P	ΔE_{00}
B1	L*	75.7±0.4	0.2±0.5	74.5±1.4	1.1±1.3	**<0.05**	3.9±0.5
	a*	-0.9±0.1		1.9±0.3			
	b*	12.8±0.1		12.5±0.5			
A1	L*	76.5±0.3	0.2±0.4	76.7±2.3	1.6±1.3	**<0.05**	3.7±0.8
	a*	-0.3±0.1		2.2±0.3			
	b*	14.1±0.2		12.9±0.7			
B2	L*	74.2±0.3	0.2±0.4	72.7±0.7	0.9±0.8	**<0.05**	2.9±0.5
	a*	0.2±0.1		2.2±0.3			
	b*	18.3±0.2		17.4±0.7			
D2	L*	69.7±0.5	0.4±0.5	67.2±0.8	1.0±0.5	**<0.05**	5.0±0.7
	a*	0.7±0.1		4.2±0.5			
	b*	13.3±0.2		13.9±0.8			
A2	L*	73.8±0.5	0.3±0.4	72.6±0.5	0.7±0.6	**<0.05**	4.2±0.4
	a*	1.1±0.1		4.3±0.3			
	b*	18.2±0.2		18.6±0.4			
C1	L*	70.8±0.5	0.3±0.5	68.9±0.9	0.9±0.5	**<0.05**	5.1±0.6
	a*	0.0±0.1		3.7±0.4			
	b*	13.8±0.2		15.2±0.5			
C2	L*	69.0±0.6	0.7±0.5	66.4±1.3	1.2±0.8	**<0.05**	4.9±0.9
	a*	1.1±0.2		4.4±0.5			
	b*	18.3±0.8		19.9±0.6			
D4	L*	66.9±0.9	0.9±0.4	66.2±0.8	1.1±1.0	0.750	3.4±0.6
	a*	1.0±0.3		3.6±0.3		**<0.05**	
	b*	19.4±0.7		21.1±0.7		0.734	
A3	L*	71.7±0.7	0.4±0.8	68.6±1.0	1.2±0.7	**<0.05**	4.9±0.6
	a*	1.8±0.2		5.3±0.5			
	b*	20.5±0.4		21.5±1.1			
D3	L*	68.9±0.5	0.3±0.5	68.3±1.0	1.2±1.1	**<0.05**	5.0±0.7
	a*	1.4±0.1		5.1±0.3			
	b*	17.2±0.1		18.9±0.5			
B3	L*	71.0±0.3	0.3±0.3	69.7±0.8	0.8±0.5	**<0.05**	4.0±0.5
	a*	1.6±0.2		5.0±0.4			
	b*	23.5±0.2		25.2±0.7			
A3.5	L*	68.9±0.5	0.3±0.6	66.0±1.0	1.1±0.7	**<0.05**	5.8±0.7
	a*	2.4±0.1		7.1±0.7			
	b*	23.0±0.3		26.3±1.1			
B4	L*	69.7±0.5	0.8±0.4	66.8±0.9	0.8±0.4	**<0.05**	5.6±0.7
	a*	2.1±0.2		6.6±0.4			
	b*	24.6±1.1		28.2±0.7			
C3	L*	66.4±0.4	0.3±0.5	62.8±1.1	1.2±0.6	**<0.05**	5.7±1.1
	a*	1.2±0.1		5.6±0.7			
	b*	18.9±0.1		21.2±0.7			

A4	L*	65.4±0.6	0.4±0.6	61.6±1.4	1.2±0.8	<**0.05**	7.1±0.9
	a*	3.2±0.1		9.4±0.5			
	b*	23.0±0.1		26.7±0.3			
C4	L*	61.2±0.6	0.4±0.6	57.0±7.4	1.0±0.5	<**0.05**	6.6±1.2
	a*	2.5±0.2		7.4±0.6			
	b*	19.3±0.3		22.5±1.0			
Total			0.5±0.6		1.1±0.8		4.9±1.7

Table 4: eLAB and SpectroShade (SS) L*a*b* mean and standard deviation (SD) values comparison, intra-device (ΔE00 eLAB and ΔE00 SS), and inter-device ΔE00 for each tab of Vita 3D Master (VM). Results in bold are statistically significant.

VM		SS	ΔE_{00} SS	eLAB	ΔE_{00} eLAB	P	ΔE_{00}
0M1	L*	81.1±0.2	0.1±0.2	78.0±1.0	0.9±0.6	**<0.05**	3.3±0.5
	a*	-0.3±0.1		0.8±0.2			
	b*	6.7±0.1		4.5±0.3			
0M2	L*	79.8±0.3	0.2±0.2	7.7±0.8	1.3±2.6	**<0.05**	3.7±3.1
	a*	-0.5±0.1		1.6±4.4			
	b*	8.0±0.1		5.7±0.4			
0M3	L*	79.2±0.1	0.1±0.2	77.2±0.9	0.9±0.7	**<0.05**	3.3±0.6
	a*	-0.7±0.0		0.8±0.2			
	b*	9.4±0.2		6.9±0.4			
1M1	L*	77.5±0.5	0.2±0.6	74.7±1.1	1.5±2.7	**<0.05**	3.9±3.1
	a*	-0.3±0.0		1.8±0.2			
	b*	12.3±0.3		10.4±0.3			
2M1	L*	72.5±0.1	0.1±0.2	71.0±1.1	1.0±0.7	**<0.05**	3.4±0.5
	a*	0.2±0.1		2.5±0.2			
	b*	13.0±0.1		12.5±0.3			
1M2	L*	77.2±0.4	0.2±0.6	75.2±1.5	1.2±0.6	**<0.05**	3.5±0.6
	a*	-0.5±0.1		1.6±0.2			
	b*	16.8±0.2		15.4±0.3			
2L1,5	L*	72.7±0.0	0.3±1.4	70.8±0.8	0.9±0.4	**<0.05**	4.1±1.0
	a*	-0.5±0.0		2.4±0.5			
	b*	15.7±1.4		16.1±0.7			
2R1,5	L*	72.2±0.3	0.3±0.2	70.3±1.2	1.1±0.5	**<0.05**	3.7±0.7
	a*	0.9±0.1		3.4±0.3			
	b*	15.1±0.1		15.0±0.5			
2M2	L*	71.8±2.0	1.4±1.4	72.0±1,3	1.2±0.6	0.053	4.0±0.5
	a*	0.3±0.4		3.1±0.3		0.062	
	b*	17.0±1.3		17.9±0.6		**<0.05**	
3M1	L*	68.1±0.2	0.2±0.2	66.0±1.3	1.2±0.9	**<0.05**	4.2±1.0
	a*	1.2±0.1		4.1±0.8			
	b*	14.2±0.1		14.5±0.5			
3L1,5	L*	67.0±0.1	0.1±0.3	65.4±0.8	1.0±0.6	**<0.05**	4.5±0.6
	a*	1.1±0.1		4.6±0.5			
	b*	18.3±0.2		19.6±0.7			
2R2,5	L*	73.4±0.4	0.2±0.5	71.0±1.0	0.9±0.5	**<0.05**	4.4±0.4
	a*	0.8±0.0		3.9±0.2			
	b*	20.9±0.1		21.3±0.3			
2L2,5	L*	72.3±0.1	0.1±0.5	71.3±1.3	1.4±0.6	**<0.05**	4.3±0.9
	a*	-0.2±0.1		3.1±0.7			
	b*	22.4±0.4		22.5±1.5			
3R1,5	L*	71.8±1.2	0.6±1.4	66.4±0.9	0.9±0.7	0.448	7.3±0.6

	a*	1.0±0.3		5.5±0.3		0.921	
	b*	15.2±0.4		17.8±0.4		0.161	
	L*	73.2±0.2		71.8±1.3			
2M3	a*	0.3±0.1	0.1±0.4	3.5±0.4	1.1±0.6	**<0.05**	4.2±0.6
	b*	22.5±0.1		23.4±0.8			
	L*	69.2±1.6		67.1±1.3		0.111	
3M2	a*	1.7±0.1	1.0±1.1	5.0±0.3	1.0±0.8	**<0.05**	4.6±0.5
	b*	20.1±0.7		20.7±0.6		0.652	
	L*	65.2±0.5		61.0±0.7			
4M1	a*	1.9±0.1	0.2±0.6	5.6±0.2	0.9±0.9	**<0.05**	5.9±0.4
	b*	15.8±0.1		15.9±0.5			
	L*	68.6±0.3		66.9±0.8			
3L2,5	a*	1.3±0.1	0.2±0.4	5.2±0.4	0.9±0.5	**<0.05**	4.8±0.4
	b*	23.3±0.1		24.9±0.6			
	L*	70.0±1.0		61.1±0.6		0.082	
3R2,5	a*	3.1±0.2	0.4±1.3	6.7±0.2	0.7±0.5	**<0.05**	5.5±0.4
	b*	25.2±0.8		24.8±0.5		0.181	
	L*	64.8±0.5		61.9±0.4		0.463	
4L1,5	a*	2.2±0.1	0.2±0.6	6.0±0.4	0.8±0.5	**<0.05**	5.3±0.5
	b*	20.1±0.2		20.9±0.8		**<0.05**	
	L*	68.5±0.1		66.3±1.1			
3M3	a*	2.5±0.1	0.3±0.4	6.0±0.4	1.2±0.6	**<0.05**	4.5±0.6
	b*	26.0±0.5		27.0±1.0			
	L*	65.0±0.4		61.9±0.8			
4R1,5	a*	3.1±0.4	0.5±0.5	7.3±0.5	0.9±0.5	**<0.05**	5.7±0.9
	b*	19.6±0.3		19.7±0.8			
	L*	65.3±0.4		62.3±0.6			
4M2	a*	2.5±0.3	0.5±0.3	7.3±0.4	0.9±0.5	**<0.05**	6.2±0.4
	b*	20.7±0.5		22.8±1.0			
	L*	60.1±0.4		55.6±1.5			
5M1	a*	3.2±0.0	0.2±0.5	7.7±0.4	1.4±0.8	**<0.05**	6.9±0.8
	b*	18.3±0.2		18.6±0.3			
	L*	65.6±0.8		61.7±0.9		0.494	
4L2,5	a*	3.5±0.2	0.4±1.1	8.0±0.8	1.1±0.6	**<0.05**	6.3±0.8
	b*	27.8±0.5		28.0±1.1		**<0.05**	
	L*	65.4±0.5		61.3±0.9			
4R2,5	a*	3.8±0.1	0.8±1.0	9.0±0.4	0.9±0.5	**<0.05**	6.9±0.7
	b*	24.5±1.6		26.1±0.8			
	L*	66.0±0.4		62.2±1.4			
4M3	a*	3.5±0.1	0.2±0.6	9.1±0.3	1.2±0.7	**<0.05**	6.9±0.8
	b*	28.1±0.1		30.3±1.0			
	L*	61.2±0.2		57.7±1.2			
5M2	a*	4.6±0.1	0.1±0.4	10.1±0.4	1.1±0.6	**<0.05**	6.9±0.8
	b*	25.1±0.3		26.1±0.5			
	L*	62.0±0.5		57.9±1.1			
5M3	a*	5.8±0.1	0.2±0.7	12.5±0.6	1.2±0.7	**<0.05**	7.9±0.9
	b*	32.2±0.4		33.5±0.7			
Total			0.5±0.8		1.1±0.9		5.0±1.7

DISCUSSION

In this study, two different methods for assessing tooth color were evaluated in vitro, SS, a spectrophotometric measurement device, and eLAB, a photographic protocol, based on their assessment of two shade guides (VC and VM). The results showed that there were statistically significant differences in L*a*b* values between the devices for the two shade guides, thus leading to the rejection of the null hypothesis.

ICC presented good to excellent values in both methods, being the lowest values for the a* component in SS for VC and eLAB for VM. These discrepancies could be attributed to inconsistencies between tabs or intrinsic variability of the batches.(23,24) The results suggest that the devices could have intrinsic variability capable of influencing color assessment, such as fabrication processes, calibration procedures, or maintenance issues.(16)

The obtained global intra-method ΔE_{00} differences above the perceptibility threshold (ΔE_{00}=0.8) were detected in eLab, however, none of the individual guides exceeded the acceptability limit (ΔE_{00}=1.8), in both shade guides. These values suggest good consistency and reproducibility in color evaluation.

Although there are high ICC values, when analysing L*a*b* values, differences were found for both shade guides, thus leading to the rejection of the null hypothesis that there are no statistically significant differences between the determined L*a*b* coordinates of the two methods in the measurement of the shade tabs of the two guides (VC and VM). The global ΔE_{00} between methods was higher than the limit of acceptability, and there were statistically significant differences between methods for all L*, a*, and b* components. These observed differences demonstrate a weak relationship between the L*, a*, and b* values between the two methods, and a correspondence between them should not be performed.

None of the values of intra-device ΔE_{00} for eLAB were above the acceptability threshold, but some of the shade tabs were higher than the perceptibility threshold. The color difference between the two methods for both shade guides was above the acceptability threshold (ΔE_{00}=1.8). Given that the devices were measuring the same shade tabs, chromatic differences should not exist. This could be related to the different methods for color acquisition, being that SS can acquire color in 3 different ways (tooth average color, thirds, or chromatic maps) and the eLAB protocol used in this study acquired measurements of the central region of each tab. In this in vitro study, the measurement of the tooth average color of the shade tab was used for SS, which could reduce the value of accuracy, when compared to the readings of the eLAB protocol. However, this data could also be related to the variation of L*a*b* values between shade guides.

Our results suggest that the correspondence of L*a*b* values between different methods to communicate L*a*b* color coordinates is not accurate. Manufacturers should consider improving standardization, so color communication can become more accurate and reproductible in a clinical context.[16]

This study intended to compare two different methods for color assessment, in a controlled environment. Although not an in vivo study, standardized shade guides were used and the reproducibility of each method was evaluated, minimizing factors that interfere with the acquisition of color. Variations between different manufacturers and batches may occur and shade tabs do not cover all colors that appear in natural teeth.

In vivo studies should be performed to verify the clinical impact on the determination of tooth color with these methods, particularly, the eLAB protocol.

CONCLUSION

Both methods presented high ICC values, which suggest good internal consistency. However, discrepancies between methods were observed in different shade tabs, higher for the a* component. Additional studies are needed to evaluate the clinical effect of this variability.

REFERENCES

1. Paravina RD, Pérez MM, Ghinea R. Acceptability and perceptibility thresholds in dentistry: A comprehensive review of clinical and research applications. *J Esthet Restor Dent*. 2019;31(2):103-112. doi:10.1111/JERD.12465

2. Dozic A, Voit NFA, Zwartser R, Khashayar G, Aartman I. Color coverage of a newly developed system for color determination and reproduction in dentistry. *J Dent*. 2010;38 Suppl 2(SUPPL. 2). doi:10.1016/J.JDENT.2010.07.004

3. Mounika A, Mandava J, Roopesh B, Karri G. Clinical evaluation of color change and tooth sensitivity with in-office and home bleaching treatments. *Indian Journal of Dental Research*. 2018;29(4):423-427. doi:10.4103/ijdr.IJDR_688_16

4. Mehl A, Bosch G, Fischer C, Ender A. In vivo tooth-color measurement with a new 3D intraoral scanning system in comparison to conventional digital and visual color determination methods. *Int J Comput Dent*. 2017;20(4):343-361. http://www.ncbi.nlm.nih.gov/pubmed/29292410

5. Pan Q, Westland S. Tooth color and whitening - digital technologies. *J Dent*. 2018;74 Suppl 1:S42-S46. doi:10.1016/J.JDENT.2018.04.023

6. Joiner A, Luo W. Tooth colour and whiteness: A review. *J Dent*. 2017;67S:S3-S10. doi:10.1016/J.JDENT.2017.09.006

7. Sampaio C, Gurrea J, Gurrea M, et al. Dental Shade Guide Variability for Hues B, C, and D Using Cross-Polarized Photography. *The International Journal of Periodontics & Restorative Dentistry*. 2018;38(April 2021):s113-s118. doi:10.11607/prd.3270

8. Hein MDT S, Modri MDT D, Westland S, Tomeček MUDr M. Objective shade matching, communication, and reproduction by combining dental photography and numeric shade quantification. Published online 2020. doi:10.1111/jerd.12641

9. Mahn E, Tortora SC, Olate B, Cacciuttolo F, Kernitsky J, Jorquera G. Comparison of visual analog shade matching, a digital visual method with a cross-polarized light filter, and a spectrophotometer for dental color matching. *J Prosthet Dent*. 2021;125(3):511-516. doi:10.1016/J.PROSDENT.2020.02.002

10. Karaman T, Altintas E, Eser B, Talo Yildirim T, Oztekin F, Bozoglan A. Spectrophotometric Evaluation of Anterior Maxillary Tooth Color Distribution According to Age and Gender. *J Prosthodont*. 2019;28(1):e96-e102. doi:10.1111/JOPR.12783

11. Sampaio CS, Atria PJ, Hirata R, Jorquera G. Variability of color matching with different digital photography techniques and a gray reference card. *Journal of Prosthetic Dentistry*. 2019;121(2):333-339. doi:10.1016/J.PROSDENT.2018.03.009

12. Liberato WF, Barreto IC, Costa PP, de Almeida CC, Pimentel W, Tiossi R. A comparison between visual, intraoral scanner, and spectrophotometer shade

matching: A clinical study. *J Prosthet Dent*. 2019;121(2):271-275. doi:10.1016/J.PROSDENT.2018.05.004

13. He WH, Park CJ, Byun S, Tan D, Lin CY, Chee W. Evaluating the relationship between tooth color and enamel thickness, using twin flash photography, cross-polarization photography, and spectrophotometer. *J Esthet Restor Dent*. 2020;32(1):91-101. doi:10.1111/JERD.12553

14. Lazar R, Culic B, Gasparik C, Lazar C, Dudea D. The accuracy of dental shade matching using cross-polarization photography. *International Journal of Computerized Dentistry*. 2019;22(4):343-351.

15. Dias S, Marques D, Silveira J, Corado D, Alves R, Mata A. Determinação da cor de diferentes escalas por dois métodos espectrofotométricos-estudo in vitro. Published online 2017. doi:10.24873/j.rpemd.2017.10.023

16. SB FD, JM LS, RM NP, AB C, A DSP da M, DN da SM. CIEL*a*b* values in vita classical and vita 3d master by two dental spectrophotometers. *Int J Prosthodont*. Published online 2021. doi:10.11607/IJP.7235

17. Farah RI, Almershed AS, Albahli BF, Al-Haj Ali SN. Effect of ambient lighting conditions on tooth color quantification in cross-polarized dental photography: A clinical study. *J Prosthet Dent*. Published online 2021. doi:10.1016/J.PROSDENT.2021.01.015

18. Ntovas P, Papazoglou E. Digital selection of composite resin shade using cross polarized photography and a standardized white balance gray reference card. *J Clin Exp Dent*. 2021;13(10):1061-1067. doi:10.4317/jced.58340

19. Kim-Pusateri S, Brewer JD, Dunford RG, Wee AG. In vitro model to evaluate reliability and accuracy of a dental shade-matching instrument. *Journal of Prosthetic Dentistry*. 2007;98(5):353-358. doi:10.1016/S0022-3913(07)60119-X

20. eLABor_aid: a new approach to digital shade management - PubMed. Accessed April 27, 2022. https://pubmed.ncbi.nlm.nih.gov/28653050/

21. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine*. 2016;15(2):155-163. doi:10.1016/J.JCM.2016.02.012

22. Paravina RD, Ghinea R, Herrera LJ, et al. Color difference thresholds in dentistry. *J Esthet Restor Dent*. 2015;27 Suppl 1(S1):S1-S9. doi:10.1111/JERD.12149

23. Lagouvardos PE, Fougia AG, Diamantopoulou SA, Polyzois GL. Repeatability and interdevice reliability of two portable color selection devices in matching and measuring tooth color. *Journal of Prosthetic Dentistry*. 2009;101(1):40-45. doi:10.1016/S0022-3913(08)60289-9

24. G Omez-Polo C, G Omez-Polo M, Mart Inez Vazquez De Parga JA, Celemin-Vi A. 3D Master Toothguide According to L*, C*, and h* Coordinates. *Wiley Periodicals, Inc Col Res Appl*. 2014;40:518-524. doi:10.1002/col.21896