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Facultad de Odontología

Especialización en Rehabilitación Oral y Prótesis Implanto Asistida

Variability in Tooth Color Selection by Different Spectrophotometers: A Systematic Review

Trabajo de titulación previo a la obtención del título de Especialista en Rehabilitación Oral y Prótesis Implanto Asistida

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Resumen: Objetivo: Evaluar la variabilidad en la precisión y fiabilidad de la selección del color dental entre diferentes espectrofotómetros.

Materiales y Métodos: Se realizó una búsqueda en las siguientes bases de datos: MEDLINE (PubMed), Google Scholar, Scopus y Web of Science. También se realizó una búsqueda manual basada en las listas de referencias de los artículos pertinentes. La selección, la extracción de datos y la evaluación de la calidad, se realizaron de forma independiente y por duplicado. En la estrategia de búsqueda, se utilizaron palabras (MeSH) en PubMed, y términos libres para los títulos y resúmenes de cada artículo. Cada palabra clave fue separó mediante el operador booleano OR para luego ser combinado con el operador booleano AND. Los tres autores participaron de forma independiente en la selección de estudios basada en los criterios de inclusión, la extracción de datos y la evaluación del sesgo. La evaluación del riesgo de sesgo en los estudios in vivo se basó en los parámetros asignados por la herramienta Newcastle-Ottawa, y el riesgo de sesgo de los estudios in vitro in vitro se clasificó aplicando los criterios ARRIVE y CONSORT modificados. Hubo una gran heterogeneidad en el diseño experimental de los artículos que se incluyeron: sin embargo, ningún artículo mencionaba o se ceñía a las indicaciones dadas por la norma ISO_TR_28642_2016 para la medición del color. Se incluyeron seis estudios, dos estudios aportaron datos sobre la precisión y la repetibilidad de los espectrofotómetros, tres aportaron datos sobre la repetibilidad, y uno proporcionó datos sobre la fiabilidad

Resultados: El proceso de selección mediante el diagrama de flujo PRISMA. La búsqueda arrojó 714 estudios. De ellos, 88 duplicados. Se excluyeron 579 estudios porque sus títulos y resúmenes no cumplían los criterios de elegibilidad. Se examinaron los textos completos de los otros 47 estudios, lo que llevó a la exclusión de 39 artículos que no cumplían los criterios de inclusión. Dos de los ocho artículos restantes se excluyeron tras aplicar los criterios ARRIVE y CONSORT MODIFICADO y los criterios de Newcastle-Ottawa. De los seis estudios incluidos en la revisión sistemática, dos examinaron la precisión y la repetibilidad de los espectrofotómetros, tres la repetibilidad y uno la fiabilidad.

Conclusiones: SpectroShade Micro y VITA Easyshade presentan una mejor variabilidad en términos de precisión, pero no presentan ventajas significativas en cuanto a fiabilidad. **Registro:** El protocolo se registró en PROSPERO (el registro prospectivo internacional de revisiones sistemáticas) con el número CRD42021268853

Palabras clave: Espectrofotómetro. Diente. Precisión. Fiabilidad. Guía de color. Exactitud.

Abstract:

Objective: To evaluate the variability in the precision and reliability of tooth color selection among different spectrophotometers.

Methods: A search was performed in the following databases: MEDLINE (PubMed), Google Scholar, Scopus, and Web of Science. A manual search was also performed based on the reference lists of the relevant articles. Screening, data extraction, and quality assessment were performed independently and in duplicate. In the search strategy, medical subject heading (MeSH) words were used in PubMed, and free terms were used for the titles and abstracts of each article. Each keyword was separated by the Boolean operator OR to later be combined with the Boolean operator AND. All three authors were independently involved in studies selection based on the inclusion criteria, data extraction, and bias assessment. The assessment of the risk of bias in the in vivo studies was based on the parameters assigned by the Newcastle–Ottawa tool, and the risk of bias of the in vitro studies was categorized by applying the modified ARRIVE and CONSORT criteria. There was great heterogeneity in the experimental design of the articles that were included: however, no article mentioned or adhered to the indications given by the ISO_TR_28642_2016 standard for color measurement. Six studies were included, two studies provided data on the precision and repeatability of the spectrophotometers, three provided data on repeatability, and one provided data on reliability.

Results: The selection process using the PRISMA flow chart. The search yielded 714 studies. Of these, 88 duplicates were excluded. A total of 579 studies were excluded because their titles and abstracts did not meet the eligibility criteria. The full texts of the other 47 studies were examined, which led to the exclusion of 39 articles that did not meet the inclusion criteria. Two of the remaining eight articles were excluded after applying the modified ARRIVE and CONSORT criteria and the Newcastle–Ottawa criteria. Of the six studies included in the systematic review, two examined the precision and repeatability of the spectrophotometers, three examined repeatability, and one examined reliability.

Conclusions: The SpectroShade Micro and VITA Easyshade show better variability in terms of precision, but they have no significant advantages in reliability.

Clinical trial registration: The protocol was registered with PROSPERO (the international prospective register of systematic reviews) under number CRD4202126885

Keywords: spectrophotometer. Tooth. Precision. Reliability. color guide. Accuracy.

INDICE

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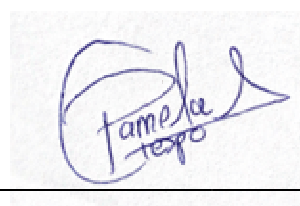

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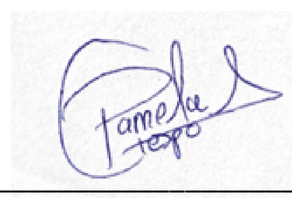

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1 INTRODUCTION

In restorative, biomimetic, and especially aesthetic dentistry, one of the most important challenges is dental color matching [1-8]. The color of the final restoration must match the color of the tooth whether the material used is composite or ceramic [9-15]. The main methods for assessing tooth color are the conventional visual method and instrumental methods [2, 10, 16-19].

The conventional visual method is best known to dentists; in this method, the color of the tooth is compared with the color guides of different commercial companies [15, 20-25]. In the instrumental method, color measurement devices, such as digital cameras, spectrophotometers, and digital scanners, are used [8, 10, 26-28]. Fatigue, age, color blindness, emotions, observer experience, ambient light, surface texture, translucency, and environmental colors are factors that affect human perception. Therefore, digital devices have been introduced to reduce or overcome these limitations [13-18, 25, 28, 29].

The most commonly used instrument for evaluating tooth color is the spectrophotometer, which measures the full spectrum of reflected or transmitted light, which is then converted into tristimulus data or CIELAB color space values [9-11, 15]. The International Commission on Illumination (CIE, for its name in French) converts the tristimulus data into L*, a*, and b* coordinates. L* represents lightness on a scale from 0 to 100 (black–white); a* and b* represent the values of hue and chroma: a* (+) red/a* (-) green, b* (+) yellow and b* (-) blue [11-15, 28-32]. The color difference between two objects is represented as ΔE, which is used in dentistry to establish thresholds of perceptibility and clinical acceptability [6, 10, 12, 23, 29, 31].

An important consideration is the ability of these instruments to reliably and accurately measure the color of teeth [11, 15, 19, 32-34]. These terms have not been explained in a concrete and clear way that could make research studies easily reproducible [13-15, 34-37]. Reliability can be defined as the degree to which repeated measurements of the same quantity, with the same measuring instrument, give the same readings [5, 8, 10, 27-29, 38]. Precision refers to how close the measurements are to each other [14-17, 21-29]. Few standardized studies have evaluated the precision and reliability of spectrophotometers for measuring tooth color, and there is no agreement among the results of individual studies. Additionally, no synthesis or general evaluation has been performed, which hinders the integration of knowledge on the subject, generating a gap between research and decision-making [8-11, 28, 29, 34, 39-41].

For this reason, the objective of this systematic review was to evaluate the variability in the precision and reliability of tooth color matching among different spectrophotometers.

2 MATERIALS AND METHODS

2.1 Protocol and registration

The protocol was registered with PROSPERO (the international prospective register of systematic reviews) under number CRD42021268853. Ethics approval was not required for this research. This systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

2.2 Search strategy

The bibliographic search was carried out by two authors (ACL and PCA) in four digital databases, MEDLINE/PubMed, Scopus, Web of Science, and Google Scholar. Full-text articles with titles compatible with the research aims were searched, without limiting the year of publication or language. In vitro, descriptive, and in vivo studies were included. In the search strategy, medical subject heading (MeSH) words were used in PubMed, and free terms were used for the titles and abstracts of each article. Each keyword was separated by the Boolean operator OR to later be combined with the Boolean operator AND. Two authors (ACL and PCA) performed the search separately, and in the case of disagreement over an article, discussion with a third researcher (DAR) was requested until a consensus was reached. The keywords used according to the PICO (population, intervention, comparison, outcomes) questions are listed in Table 1.

Table 1. Digital databases and search strategies.

PUBMED	
P	("dental color"[MeSH Terms] OR "dental color" OR "tooth color"[MeSH Terms] OR "tooth color" OR "shade guide"[Title/Abstract] OR "shade matching"[Title/Abstract])
I	("tooth spectrophotometer"[Title/Abstract] OR "easyshade"[Title/Abstract] OR "degudent"[Title/Abstract] OR "cristaleye"[Title/Abstract] OR "spectroshade"[Title/Abstract] OR "shade pilot"[Title/Abstract])
C	**#1 AND #2 AND #3**
O	("delta E"[Title/Abstract] OR "ΔE"[Title/Abstract] OR "cielab"[Title/Abstract] OR "ciede2000"[Title/Abstract])
SCOPUS	
P	TITLE-ABS-KEY("dental color" OR "tooth color" OR "shade guide" OR "shade matching")
I	("tooth spectrophotometer" OR "easyshade" OR "degudent" OR "cristaleye" OR "spectroshade" OR "shade pilot")
C	**#1 AND #2 AND #3**

O	("delta E" OR "ΔE" OR "cielab" OR "ciede2000")
WOS	
P	TI=("dental color" OR "tooth color" OR "shade guide" OR "shade matching")
I	("tooth spectrophotometer" OR "easyshade" OR "degudent" OR "cristaleye" OR "spectroshade" OR "shade pilot")
C	**#1 AND #2 AND #3**
O	("delta E" OR "ΔE" OR "cielab" OR "ciede2000")
GOOGLE	
P	in tittle: ("dental color" OR "tooth color" OR "shade guide" OR "shade matching")
I	("tooth spectrophotometer" OR "easyshade" OR "degudent" OR "cristaleye" OR "spectroshade" OR "shade pilot")
C	**#1 AND #2 AND #3**
O	("delta E" OR "ΔE" OR "cielab" OR "ciede2000")

2.3 Eligibility criteria

Articles that mentioned the difference in color coordinates ΔE, evaluated precision (repeatability or reproducibility) and reliability between different spectrophotometers and measured the color of live teeth, extracted teeth, and used color guides were included in the review.

The following articles were excluded: articles that did not compare more than one spectrophotometer; articles that involved the shade of unhealthy dental organs, tooth whitening, materials milled in CAD-CAM, dental organs with endodontics, or stained teeth (e.g., by tetracycline, enamel hypoplasia, or fluorosis, among others); and articles that used color guides that were not intended for dental use.

2.4 Criteria and selection

Studies were screened in two phases. In phase 1, the studies found in the searches (excluding duplicates) were independently reviewed by two researchers (ACL and PCA) by reading the titles and abstracts to determine whether the studies met the inclusion criteria. In phase 2, the full text of each article selected for its title and abstract was read, and the modified ARRIVE and CONSORT criteria were applied [29] (Fig. 1). The risk of bias was assessed to evaluate the methodological quality of the article in terms of its correct execution as well as the structure of the title, abstract, introduction, methods, results, discussion, and conclusions [30]. A manual search of all the selected articles was performed with respect to the inclusion criteria. Any disagreement about the inclusion of an article was resolved by discussion with the third author (DAR).

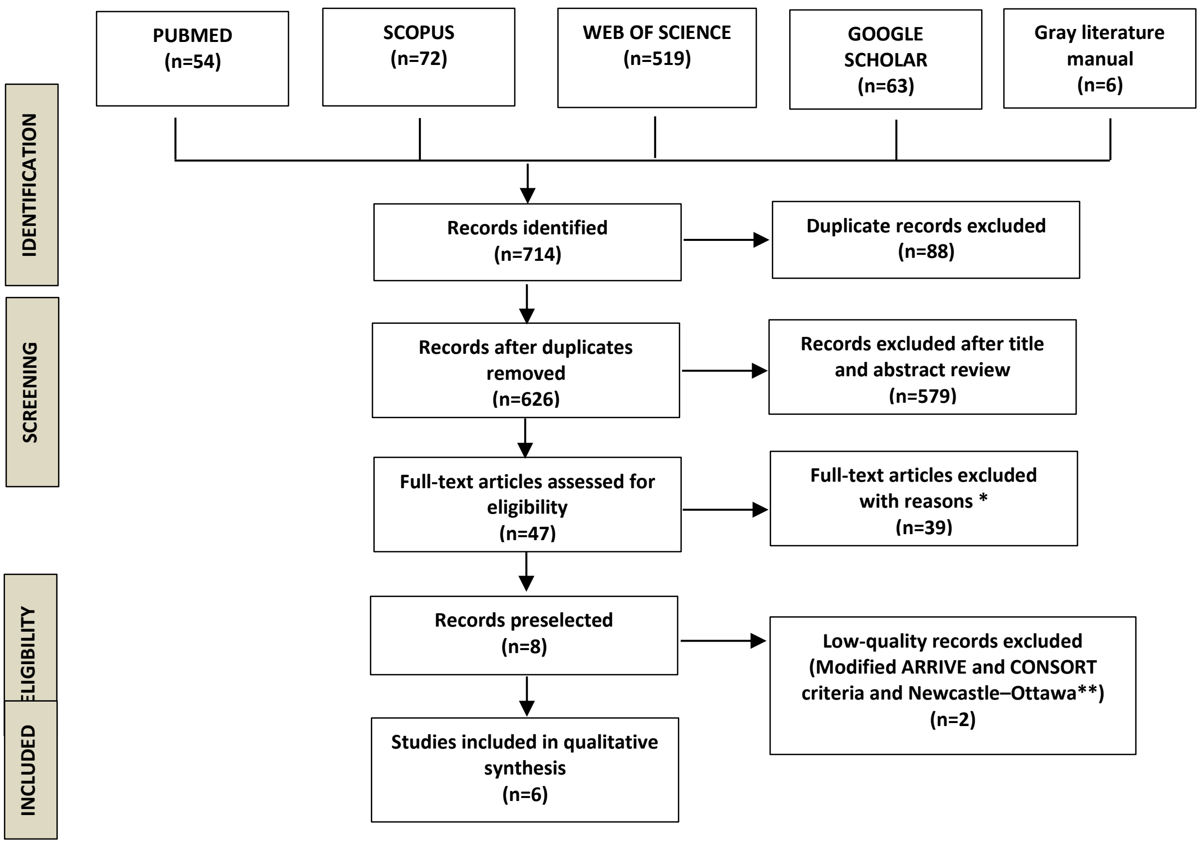

Fig. 1. The PRISMA flow diagram. From [24]
*: 30 only used a spectrophotometer, 9 did not compare spectrophotometers

**: Did not describe the sample size calculation, did not have the same observer, or did not specify the calibration of the operator and the instrument. For more information, visit www.prisma-statement.org

2.5 Selection, management, and data collection

The data were extracted independently by two authors (ACL and PCA). The full-text articles selected for inclusion were managed using a standardized form in digital format (Office Excel 2016 software, Microsoft Corporation, Redmond, WA, USA).

The authors compiled information on the authors, year of publication, study design, sample size, spectrophotometer used, results, conclusions, and risk of bias.

2.6 Assessment of risk of bias and methodological quality

The assessment of the risk of bias in the in vivo studies was based on the parameters assigned by the Newcastle–Ottawa tool, as follows: (a) selection (representativeness, selection, ascertainment, and demonstration); (b) comparability; and (c) outcome (assessment, follow-up, and adequacy of follow-up) [36].

If the article was assigned 3 to 4 stars in the selection category, 1 or 2 stars in the comparability category, and 2 or 3 stars in the outcome/exposure category, it was classified as good quality. If the article was assigned 2 stars in the selection category, 1 or 2 stars in the comparability category, and 2 or 3 stars in the outcome/exposure category, it was classified as fair quality. The article was classified as poor quality if it scored 0 or 1 star in the selection category, 0 stars in the comparability category, or 0 or 1 star in the outcome/exposure category.

The risk of bias of the in vitro studies was categorized as described in a previous study [29] according to the following five parameters: (a) standardization of sampling procedures; (b) single operator; (c) description of the sample size calculation; (d) calibration of the instrument used according to the standards and specifications; and (e) observer calibration. If the article clearly reported on a parameter, it received a score of 0 for that parameter. If a specific parameter was reported but reported unclearly, the score was 1. If it was not possible to find this information, the score was 2.

Articles with a score of 0 to 3, 4 to 7, and 8 to 10 were classified as having a low, moderate, and high risk of bias, respectively. The risk of bias of the in vitro and in vivo studies included in the review was evaluated independently, in duplicate, by two authors (ACL and PCA), and any disagreement in the evaluation was resolved by consensus.

2.7 Analysis and synthesis of data

There was great heterogeneity in the experimental design of the articles that were included, including in the sample size, digital instruments used, color guides, and dentition at the time of color acquisition. No articles mentioned or adhered to the indications given by the ISO_TR_28642_2016 standard for color measurement [32].

3 RESULTS

3.1 Search and selection

The selection process using the PRISMA flow chart is shown in Fig. 1. The search yielded 714 studies. Of these, 88 duplicates were excluded. A total of 579 studies were excluded because their titles and abstracts did not meet the eligibility criteria. The full texts of the other 47 studies were examined, which led to the exclusion of 39 articles that did not meet the inclusion criteria. Two of the remaining eight articles were excluded after applying the modified ARRIVE and CONSORT criteria and the Newcastle–Ottawa criteria. Of the six studies included in the systematic review, two examined the precision and repeatability of the spectrophotometers, three examined repeatability, and one examined reliability (Table 2).

Table 2. Summary of the studies included in the systematic review.

N°	Author	Year	Type of study	Sample	Color guide	Spectrophotometer	Results: Mean	Results: SD	Conclusions
1	Tsiliagkou *et al*. [28]	2016	In vitro	10 shade tabs	VITA Classic	VITA Easyshade	4.155e*	3.77e*	**(ES) Repeatability** low under standardized and free-hand conditions
						SpectroShade Micro	1.662e*	1.88e*	**(ES) Precision** good–fair under standardized condition and low under free-hand condition
						ShadeVision	2.032e*	3.19e*	**(SS) Repeatability** good under standardized and free-hand conditions
					VITA 3D Master	VITA Easyshade	6.496ma*	5.07ma*	**(SS) Precision** high under free-hand and standardized conditions
						SpectroShade Micro	1.682ma*	1.49ma*	**(SV) Repeatability** low under standardized condition
						ShadeVision	2.517ma*	2.07ma*	**(SV) Precision** moderate under standardized condition
2	Khurana *et al*. [11]	2007	In vivo	120 teeth	VITA classic	VITA Easyshade SpectroShade Micro ShadeVision	Kappa 0.50 Kappa 0.80 Kappa 0.597		SS had better repeatability than ES and SV
3	Dozic *et al*. [25]	2007	In vivo	25 natural teeth	VITA Lumin	ShadeScan Ikam ShadeEye	0.5p* - 0.5f* 0.6p* - 0.5f* 1.7p* - 1.9f*		ES was the most reliable instrument both in vitro and in vivo
						VITA Easyshade IdentaColor II	0.0p* - 0.0f* 1.0p* - 2.2f*		No significant difference in operator precision or accuracy
			In vitro	5 shade tabs		ShadeScan Ikam	1.5p* - 1.8f* 0.4p* - 2.9f*		Most devices were more reliable in vitro than in vivo
						ShadeEye VITA Easyshade IdentaColor II	0.7p* - 2.4f* 0.4p* - 2.5f* 0.7p* - 3.4f*		SE and IC were less reliable than ES and IK
4	Llena *et al*. [33]	2011	In vivo	60 natural teeth	VITA classic	VITA Easyshade	2.28	2.25	ES and SS showed excellent repeatability and can be used in the office to evaluate tooth color or color changes after treatment
					VITA 3D Master	SpectroShade Micro	1.69 p = 0.184	4.32	

5	Panagiotis *et al.* [19]	2007	In vitro	31 extracted teeth	VITA classic	VITA Easyshade	0.714-0.756 p = 0.731		ES: greater repeatability in L* value
					VITA 3D Master	ShadeEye	0.894-0.813 p = 0.255		No difference in reliability between spectrophotometers
							Color difference 0.866-0.640 p = 0.036		No difference in repeatability with color guide
6	Kim-Pusateri *et al.* [34]	2004	In vitro	62 shade tabs	VITA classic	SpectroShade Micro		15.59p* - 0.69f*	Highest reliability with SV, followed by SS
						ShadeVision		1.44p* - 0.40f*	and ES and finally SSc
					VITA 3D Master	ShadeScan		1.89p* - 1.33f*	Greatest precision with ES, followed by SV,
						VITA Easyshade		1.05p* - 0.75f*	SS, and SSc
							Difference z = 0.15f*	15.59p* - 0.69f*	
							Difference z = 6.53p*		

e* standardized, **ma*** free-hand, **p*** precision, **f*** reliability, **ES** Easyshade, **SS** SpectroShade, **SV** ShadeVision, **SSc** ShadeScan, **SE** ShadeEye, **IK** Ikam, **IC** IdentaColor II

3.2 Assessment of risk of bias and methodological quality

The three in vivo studies included in the systematic review presented a fair risk of bias. The three in vitro studies included had a low risk of bias. No article had a high risk of bias (Fig. 2a and b and Table 3a and b). The risks of bias most frequently found in the studies originated from the calculation of the sample size and the calibration of the instrument according to the manufacturer's specifications.

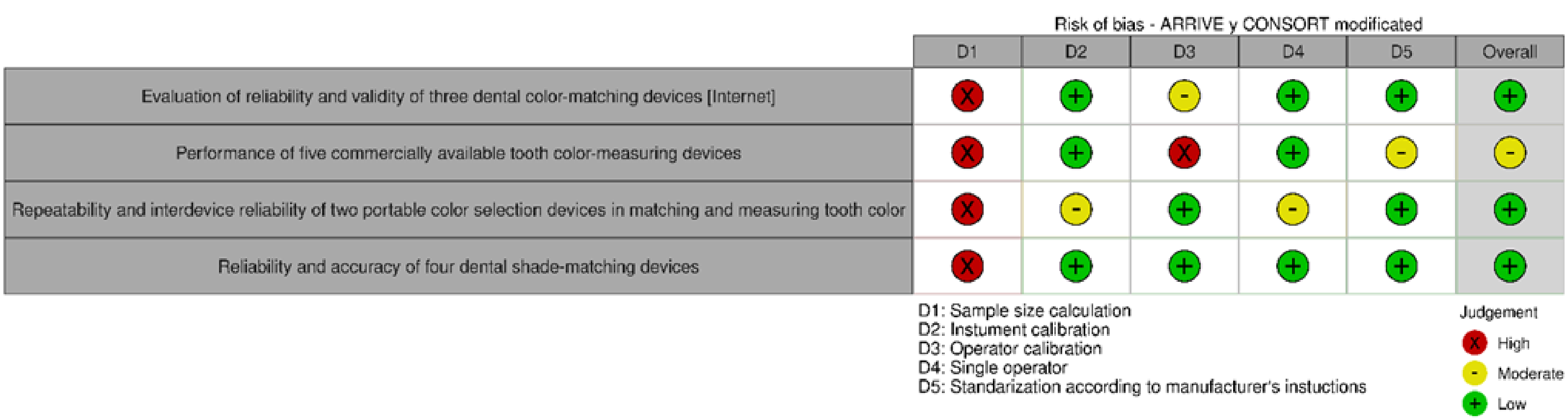

Fig. 2a. Summary of the assessment of the risk of bias of in vitro studies

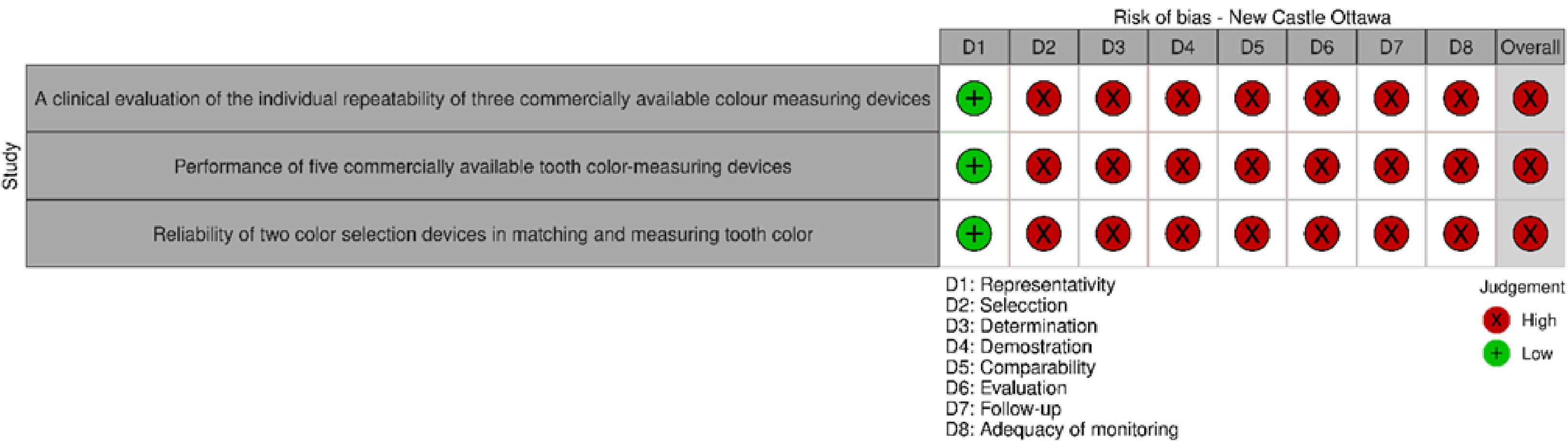

Fig. 2b. Summary of the assessment of the risk of bias of in vivo studies

Table 3a. Risks of bias of the studies included in the systematic review.

N	Title	Author	Year	Type of study	Newcastle–Ottawa								Quality
					Selection				Outcome				
					Representativeness	Selection	Ascertainment	Demonstration	Comparability	Assessment	Follow-up	Adequacy of follow-up	
2	A clinical evaluation of the individual repeatability of three commercially available color-measuring devices	Khurana *et al*. [11]	2007	In vivo	*	-	-	-	-	-	-	-	Poor
3	Performance of five commercially available tooth color-measuring devices	Dozić *et al*. [25]	2007	In vitro/in vivo	*	-	-	-	-	-	-	-	Poor
4	Reliability of two color selection devices in matching and measuring tooth color	Llena C. *et al*. [33]	2011	In vivo	*	*	-	*	-	-	-	-	Moderate

4 DISCUSSION

Color differences that can be detected by the human eye are limited to some extent. The threshold of acceptability and the clinical perceptibility of color differences have been controversial topics in the literature [8, 14-19, 34, 41-45]. Ruyter et al. [38] established the threshold of clinical acceptability at 3.3, which means that color differences with $\Delta E \leq 3.3$ are clinically acceptable, while differences with $\Delta E > 3.4$ will be rejected.

To overcome the limitations of human visual color matching, digital color measurement devices were created and are considered to represent an important technological advance in dentistry [19, 21-40, 46-51]. It is crucial that these devices have high precision and reliability. Different studies on the precision and reliability of dental color-matching devices have presented contradictory results with the same devices [21, 34, 37-41, 52, 53]. The lack of a gold standard for measuring and comparing color differences is the main drawback to investigating the precision and reliability of these devices [15, 22, 54-57].

The results obtained with this systematic review, whose objective was to evaluate the variability in the precision and reliability among different spectrophotometers, show that the VITA Easyshade and the SpectroShade Micro have excellent repeatability and reliability [11, 25]. Two of the six articles included showed no significant difference in reliability or repeatability between the VITA Easyshade and SpectroShade Micro [41, 58, 59]. Llena et al. [33] measured the color of 60 natural anterior teeth and obtained an average of 2.28 for the VITA Easyshade and 1.69 for the SpectroShade Micro; Lagouvardos et al. [19] performed an in vitro study in which the color of 31 extracted anterior teeth was measured with the VITA Easyshade and ShadeEye and obtained an average of 0.714 and 0.894, respectively. In an in vitro study, Kim-Pusateri et al. [34] found the best reliability for the ShadeVision, with a standard deviation of 0.40, followed by the SpectroShade Micro, with a standard deviation of 0.69, and the VITA Easyshade, with a standard deviation of 0.75. The VITA Easyshade had the greatest shade-matching accuracy, with a standard deviation of 1.05. However, in an in vivo and in vitro study, Dozić et al. [25] found greater reliability when using the VITA Easyshade, with a value of 0.0. In an in vivo study, Khurana et al. [11] analyzed the repeatability of spectrophotometers in measuring tooth color and found high values for the SpectroShade (kappa = 0.80), indicating a substantial degree of agreement. In an in vitro study, Tsiliagkou et al. [28] determined the precision and repeatability of three spectrophotometers under two conditions: free-hand and standardized.

They found better results for the SpectroShade, with an average of 1.682 and 1.662, respectively. The VITA Easyshade presented low repeatability under both the standardized and free-hand conditions, at 4.155 and 6.496, respectively, and between good and fair precision under both conditions [21, 39, 60].

This study is not free of limitations. Some of these limitations are mentioned below. First, there are no validated criteria for evaluating the methodological quality and risk of bias of in vitro studies; we chose to apply the modified ARRIVE and CONSORT criteria [29]. Second, the studies did not follow a standardized protocol in the experimental phase according to ISO_TR_28642_2016; instead, they were governed by the specifications of the manufacturer of each spectrophotometer [32]. Third, there is the possibility of variations in the shade tabs of color guides from the same manufacturer. Fourth, the samples were small, and most studies were performed in vitro, which widens the margin of error in the clinical setting.

5 CONCLUSION

Based on the results of this systematic review, the following conclusions were drawn:

1. The SpectroShade Micro and VITA Easyshade show better variability in terms of precision, but they have no significant advantages in reliability.

2. Reliability and precision data are useful for comparing these devices in vitro and can predict their performance in a clinical setting.

3. To improve the quality of future research, it is suggested to perform in vivo experimental tests using larger samples and standardized protocols.

LIST OF ABBREVIATIONS

CIE: The International Commission on Illumination

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

ETHICS APPROVAL

Not applicable

CONSENT FOR PUBLICATION

Not applicable

AVAILABILITY OF DATA AND MATERIALS

The data supporting the findings with author (A.K.C.L.)

FUNDING

This work was self-financed.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

STANDARDS OF REPORTING

STROBE guideline has been followed.

REFERENCES

[1] Hugo B, Witzel T, Klaiber B. Comparison of in vivo visual and computer-aided tooth shade determination. Clin Oral Investig. 2005 Dec;9(4):244-50.

[2] Paravina RD, Ghinea R, Herrera LJ, *et al*. Color difference thresholds in dentistry. J Esthet Restor Dent. 2015 Mar-Apr;27 Suppl 1:S1-9.

[3] Tam WK, Lee HJ. Dental shade matching using a digital camera. J Dent. 2012 Dec;40:e3-10.

[4] Reyes J, Acosta P, Ventura D. Repeatability of the human eye compared to an intraoral scanner in dental shade matching. Heliyon. 2019 Jul;5(7):e02100.

[5] Gurrea J, Gurrea M, Bruguera A, *et al*. Evaluation of dental shade guide variability using cross-polarized photography. Int J Periodontics Restorative Dent. 2016 Sep-Oct;36(5):e76-81.

[6] Chitrarsu VK, Chidambaranathan AS, Balasubramaniam M. Analysis of shade matching in natural dentitions using intraoral digital spectrophotometer in LED and filtered LED light sources. J Prosthodont. 2019 Jan;28(1):e68-73.

[7] 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. Rev Port Estomatol Med Dent Cir Maxilofac. 2017 Oct;58:168-74.

[8] Oh WS, Pogoncheff J, O'Brien WJ. Digital computer matching of tooth color. Materials (Basel). 2010 May;3(6):3694-9.

[9] Klotz AL, Habibi Y, Corcodel N, Rammelsberg P, Hassel AJ, Zenthöfer A. Laboratory and clinical reliability of two spectrophotometers. J Esthet Restor Dent. 2018 Mar;34(2):369-73.

[10] Rutkūnas V, Dirsė J, Bilius V. Accuracy of an intraoral digital scanner in tooth color determination. J Prosthet Dent. 2020 Feb;123(2):322-9.

[11] Khurana R, Tredwin CJ, Weisbloom M, Moles DR. A clinical evaluation of the individual repeatability of three commercially available colour measuring devices. Br Dent J. 2007 2007/12;203(12):675-80.

[12] Bahannan SA. Shade matching quality among dental students using visual and instrumental methods. J Dent. 2014 Jan;42(1):48-52.

[13] Alshiddi IF, Richards LC. A comparison of conventional visual and spectrophotometric shade taking by trained and untrained dental students. Aust Dent J. 2015 May;60(2):176-81.

[14] Meireles SS, Demarco FF, Santos IS, Dumith SC, Bona AD. Validation and reliability of visual assessment with a shade guide for tooth-color classification. Oper Dent. 2008 Mar;33(2):121-6.

[15] Horn DJ, Bulan-Brady J, Hicks ML. Sphere spectrophotometer versus human evaluation of tooth shade. J Endod. 1998 Dec;24(12):786-90.

[16] Rodrigues S, Shetty SR, Prithviraj DR. An evaluation of shade differences between natural anterior teeth in different age groups and gender using commercially available shade guides. J Indian Prosthodont Soc. 2012 Jun;12(4):222-30.

[17] Xu BT, Zhang B, Kang Y, Wang YN, Li Q. Applicability of CIELAB/CIEDE2000 formula in visual color assessments of metal ceramic restorations. J Dent. 2012 Jul;40 Suppl 1:e3-9.

[18] Gómez-Polo C, Muñoz MP, Lorenzo Luengo MC, Vicente P, Galindo P, Martín Casado AM. Comparison of the CIELab and CIEDE2000 color difference formulas. J Prosthet Dent. 2016 Jan;115(1):65-70.

[19] Lagouvardos PE, Fougia AG, Diamantopoulou SA, Polyzois GL. Repeatability and interdevice reliability of two portable color selection devices in matching and measuring tooth color. J Prosthet Dent. 2009 Jan;101(1):40-5.

[20] Smith RN, Collins LZ, Naeeni M, *et al*. The in vitro and in vivo validation of a mobile non-contact camera-based digital imaging system for tooth colour measurement. J Dent. 2008 Jan;36:15-20.

[21] Bona AD, Barrett AA, Rosa V, Pinzetta C. Visual and instrumental agreement in dental shade selection: three distinct observer populations and shade matching protocols. Dent Mater. 2009 Feb;25(2):276-81.

[22] Igiel C, Lehmann KM, Ghinea R, *et al*. Reliability of visual and instrumental color matching. J Esthet Restor Dent. 2017 Jul;29(5):303-8.

[23] Chen H, Huang J, Dong X, *et al*. A systematic review of visual and instrumental measurements for tooth shade matching. Quintessence Int. 2012 Sep;43(8):649-59.

[24] Ishikawa-Nagai S, Yoshida A, Sakai M, Kristiansen J, Da Silva JD. Clinical evaluation of perceptibility of color differences between natural teeth and all-ceramic crowns. J Dent. 2009 Jan;37:e57-63.

[25] Dozić A, Kleverlaan CJ, El-Zohairy A, Feilzer AJ, Khashayar G. Performance of five commercially available tooth color-measuring devices. J Prosthodont. 2007 Mar;16(2):93-100.

[26] Khashayar G, Dozic A, Kleverlaan CJ, Feilzer AJ. Data comparison between two dental spectrophotometers. Oper Dent. 2012 2012/01/01;37(1):12-20.

[27] Chang JY, Chen WC, Huang TK, *et al*. Evaluation of the accuracy and limitations of three tooth-color measuring machines. J Dent Sci. 2015 Mar;10(1):16-20.

[28] Tsiliagkou A, Diamantopoulou S, Papazoglou E, Kakaboura A. Evaluation of reliability and validity of three dental color-matching devices. Int J Esthet Dent. 2016 Jul;11(1):110-24.

[29] Astudillo-Rubio D, Delgado-Gaete A, Bellot-Arcís C, Montiel-Company JM, Pascual-Moscardó A, Almerich-Silla JM. Mechanical properties of provisional dental materials: a systematic review and meta-analysis. PLoS One. 2018 Feb;13(2):e0193162.

[30] Wells GA, Shea B, O'Connell D, *et al*. Newcastle-Ottawa quality assessment scale. Canada: Ottawa Hospital Research Institute 2014.

[31] Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009 Jul;6(7):e1000097.

[32] Report T. Technical report ISO / Tr. Measurement. 2004; 2004:14345.

[33] Llena C, Lozano E, Amengual J, Forner L. Reliability of two color selection devices in matching and measuring tooth color. J Contemp Dent Pract. 2011 Jan;12(1):19-23.

[34] Kim-Pusateri S, Brewer JD, Davis EL, Wee AG. Reliability and accuracy of four dental shade-matching devices. J Prosthet Dent. 2009 Mar;101(3):193-9.

[35] Van Der Burgt TP, Ten Bosch JJ, Borsboom PCF, Plasschaert AJM. A new method for matching tooth colors with color standards. J Dent Res. 1985 May;64(5):837-41.

[36] Sarafianou A, Kamposiora P, Papavasiliou G, Goula H. Matching repeatability and interdevice agreement of 2 intraoral spectrophotometers. J Prosthet Dent. 2012 Mar;107(3):178-85.

[37] Thoma DS, Gamper FB, Sapata VM, Voce G, Hämmerle CHF, Sailer I. Spectrophotometric analysis of fluorescent zirconia abutments compared to “conventional” zirconia abutments: a within subject controlled clinical trial. Clin Implant Dent Relat Res. 2017 Apr;19(4):760-6.

[38] Ruyter IE, Nilner K, Möller B. Color stability of dental composite resin materials for crown and bridge veneers. Dent Mater. 1987 Oct;3(5):246-51.

[39] Da Silva JD, Park SE, Weber HP, Ishikawa-Nagai S. Clinical performance of a newly developed spectrophotometric system on tooth color reproduction. J Prosthet Dent. 2008 May;99(5):361-8.

[40] Öngül D, Şermet B, Balkaya MC. Visual and instrumental evaluation of color match ability of 2 shade guides on a ceramic system. J Prosthet Dent. 2012 Jul;108(1):9-14.

[41] Igiel C, Weyhrauch M, Wentaschek S, Scheller H, Lehmann KM. Dental color matching: a comparison between visual and instrumental methods. Dent Mater J. 2016;35(1):63-9.

[42] Elamin HO, Abubakr NH, Ibrahim YE. Identifying the tooth shade in group of patients using Vita Easyshade. Eur J Dent. 2015 Apr-Jun;9(2):213-7.

[43] Ratzmann A, Treichel A, Langforth G, Gedrange T, Welk A. Experimental investigations into visual and electronic tooth color measurement. Biomed Tech (Berl). 2011 Apr;56(2):115-22.

[44] Perroni AP, Bergoli CD, Dos Santos MBF, Moraes RR, Boscato N. Spectrophotometric analysis of clinical factors related to the color of ceramic restorations: a pilot study. J Prosthet Dent. 2017 Nov;118(5):611-6.

[45] Paul S, Peter A, Pietrobon N, Hämmerle CH. Visual and spectrophotometric shade analysis of human teeth. J Dent Res. 2002 Aug;81(8):578-82.

[46] Park JH, Lee YK, Lim BS. Influence of illuminants on the color distribution of shade guides. J Prosthet Dent. 2006 Dec;96(6):402-11.

[47] Luo W, Naeeni M, Platten S, *et al*. The in vitro and in vivo reproducibility of a video-based digital imaging system for tooth colour measurement. J Dent. 2017 Dec;67s:S15-9.

[48] 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 Feb;121(2):271-5.

[49] Li Q, Wang YN. Comparison of shade matching by visual observation and an intraoral dental colorimeter. J Oral Rehabil. 2007 Nov;34(11):848-54.

[50] Dancy WK, Yaman P, Dennison JB, O'Brien WJ, Razzoog ME. Color measurements as quality criteria for clinical shade matching of porcelain crowns. J Esthet Restor Dent. 2003 May;15(2):114-21; discussion 22.

[51] Tabatabaian F, Beyabanaki E, Alirezaei P, Epakchi S. Visual and digital tooth shade selection methods, related effective factors and conditions, and their accuracy and precision: a literature review. J Esthet Restor Dent. 2021 Dec;33(8):1084-104.

[52] Parameswaran V, Anilkumar S, Lylajam S, Rajesh C, Narayan V. Comparison of accuracies of an intraoral spectrophotometer and conventional visual method for shade matching using two shade guide systems. J Indian Prosthodont Soc. 2016 Oct-Dec;16(4):352-8.

[53] 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 Jan;32(1):91-101.

[54] Kim HK. A study on the color distribution of natural teeth by age and gender in the Korean population with an intraoral spectrophotometer. J Esthet Restor Dent. 2018 Sep;30(5):408-14.

[55] 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 Mar;125(3):511-6.

[56] Lehmann KM, Igiel C, Schmidtmann I, Scheller H. Four color-measuring devices compared with a spectrophotometric reference system. J Dent. 2010 Jul;38 Suppl 2:e65-70.

[57] Kourtis SG, Tripodakis AP, Doukoudakis AA. Spectrophotometric evaluation of the optical influence of different metal alloys and porcelains in the metal-ceramic complex. J Prosthet Dent. 2004 Nov;92(5):477-85.

[58] Olms C, Setz JM. The repeatability of digital shade measurement--A clinical study. Clin Oral Investig. 2013 May;17(4):1161-6.

[59] Emery KJ, Volbrecht VJ, Peterzell DH, Webster MA. Variations in normal color vision. VI. Factors underlying individual differences in hue scaling and their implications for models of color appearance. Vision Res. 2017 Dec;141:51-65.

[60] Gómez-Polo C, Gómez-Polo M, Celemin-Viñuela A, Martínez Vázquez De Parga JA. Differences between the human eye and the spectrophotometer in the shade matching of tooth colour. J Dent. 2014 Jun;42(6):742-5.