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Accuracy, Repeatability and Reproducibility of Digital Intraoral Scanner for Shade Selection: Current Status of the Literature

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ABSTRACT

Statement of the problem: *Recently, several intraoral scanners developed initially for digital impression have added a tool for simultaneous color measurement of teeth.*

Aim: *The goal of this systematic review was to assess the accuracy, repeatability and reproducibility of digital intraoral scanner for shade selection and to verify whether intraoral optical scanning devices can be used to determine the color of restorations without requiring additional conventional color-measurement methods.*

Material and Methods: *An independent electronic search of the literature was performed with the PubMed search engine, the Cochrane library and Science Direct database by multiple investigators. Studies published in peer-reviewed journals up to 30th August 2018 were included. No time limitation was applied. The keywords used were: intraoral scanner, intraoral digital scanner, color, color measurement, shade and shade selection.*

Results: *The first search through the three databases provided 912 papers. Only three papers met the inclusion criteria. Only one intraoral scanner was tested clinically. No significant difference was found between color measurements made by Trios® Color and the conventional, visual method and digital devices, in terms of accuracy and repeatability.*

Conclusion: *Within the limitations of this review, it can be concluded that intraoral scanner Trios color could be an alternative to other methods for shade selection. Further investigations are necessary.*

Keywords

Intraoral scanner, Shade selection, Accuracy, Repeatability, Reproducibility.

Introduction

In recent years, increased patient aesthetic expectations have brought about closer scrutiny of shade taking and communication processes with the aim of increasing the chances of success of obtaining good indirect restoration appearance [1].

The most popular method for shade matching is the visual method using tooth form shade tabs [2]. This process is subjective and many variables may affect the results: the surrounding illumination, the angle of view of the tooth and the tab, clothing, make-up and the chromatic perception of the dentist such as previous eye exposure and metamerism [3-5].

To avoid these inconsistencies, several electronic devices for color assessment such as spectrophotometers, colorimeters and digital cameras have been developed, since the early 1970s [6].

Otherwise, one of the latest innovations in digital prosthodontics has been the introduction of intraoral scanners, chairside devices that scan the patient's dentition as an alternative to the use of conventional impression materials [7].

Recently, a new system developed for digital impression taking has added a tool for teeth shade measurement using a high definition camera included into a single handheld digital scanner. This direct in vivo scanning of the teeth with LED light and computer software calculate the best shade for the restoration and this shade can be directly transferred to the dental technician together with the digital impression of the tooth. Thus, CAD-CAM crown can be fabricated with the most optimal shade [8].

Such innovation will be very beneficial for the dentist, the dental technician and the patient because it combines several functions in one digital instrument, in order to work with time and cost saving in mind while recording all information required to produce dentures in one dataset [9].

The aim of this systematic review was to assess the accuracy, repeatability and reproducibility of digital intraoral scanner for shade selection and to verify whether intraoral optical scanning devices could be used to determine the color of restorations without requiring additional conventional color-measurement methods. The protocol was not registered before starting the systematic review.

Material and Method

PICO question

This review aimed to systematically retrieve and analyze studies investigating the effectiveness of shade measurements using an intraoral digital scanner. The Participants, Interventions, Comparisons and Outcomes (PICO) principle was applied during the investigation. Specifically, "Participants" included patients with natural, vital, intact teeth; "Interventions" were color measurements with intraoral scanner, Comparisons were with visual assessment and other shade- determining devices. "Outcome" was the accuracy, repeatability and reproducibility of shade measurements using an intraoral digital scanner.

Definitions

Accuracy, repeatability, and reproducibility appraise the reliability of a measurement. Accuracy is calculated by comparing a testing instrument to a reference device that is considered to be correct [10]. The term 'validity' has also been used to describe such parameter [11]. Repeatability of a measuring instrument is assessed with the comparison of repeated measures of the same specimen [10] while reproducibility is determined by the interexaminer agreement [12].

Search strategy

An independent electronic search of the literature was performed with the PubMed search engine, the Cochrane library and Science Direct database by multiple investigators. Studies published in peer-reviewed journals up to 30th August 2018 were included. No time limitation was applied. The keywords used were: intraoral scanner, intraoral digital scanner, color, color measurement, shade and shade selection.

The search strategy followed to investigate each database is shown in Table 1.

Database	Search strategy	Results
Pubmed	(((((intraoral scanner) OR intraoral digital scanner)) AND ((((shade) OR shade selection) OR color) OR color measurement)	13
Cochrane library	'intraoral scanning' OR 'intraoral scanner' OR 'intraoral digital scanner'	81
Science direct	Intraoral scanner and shade, Intraoral scanner and shade selection, Intraoral scanner and color	816

Table 1: Search strategy for each database and relative results.

Then a hand search was done to identify any other study on shade selection using digital intraoral scanner. Papers referenced in the selected studies were added to the reviewed literature if pertinent.

Study selection

Two independent reviewers (H.M, M.E) initially scanned of the titles and abstracts according to the inclusion and exclusion criteria. Then, the full texts of qualified articles were obtained for independent assessment and any disagreement was solved in consensus via discussion or by a third reviewer (A.B). The inclusion and exclusion criteria were presented as follows.

Eligibility criteria

In order to be included in the review, the paper had to meet the following criteria: 1. To be a study comparing shade selection by intraoral scanner and visual assessment or other digital devices; 2. To be a study assessing any of the following outcomes: accuracy, repeatability and reproducibility of shade selection; 3. To report details on the materials and methods; 4. To be English-language article or bilingual article with English as one of the languages.

Conversely, the exclusion criteria were stated as follows: 1. Dual publications; 2. In vitro studies.

Data items

The following data were extracted: sample size, compared methods, investigators, area of color determination, recorded measurements, assessed parameters, outcomes and conclusions.

Results

Figure 1 presents a flow chart of article selection. From the items retrieved by the keyword-based search of databases, duplicates and any study not dealing with shade selection with intraoral scanner were eliminated. Three papers were identified as relevant [8,9,13].

Only one type of intraoral scanner was evaluated in the three studies: The TRIOS® Color (3Shape, Holmens Kanal, Copenhagen, DK). All studies compared color measurement of the trios color with visual assessment and different types of spectrophotometers. The methodological characteristics and outcomes of the included studies are displayed in Table 2.

Author, year	Gotfredsen[8], 2015	Brandt[9], 2017	Mehl[13], 2017
Sample	87 teeth (two maxillary incisors and the canine from 29 patients)	107 natural medial incisors (tooth 11 or 21)	40 teeth (tooth 11 and tooth 13)
Compared methods/ devices	+ Visual assessment with Vita 3DMASTER ® + TRIOS Pod Color-P13) + MHT SpectroShadeTM (Spectrophotometer)	+ Visual assessment by a dentist Visual assessment by a dental technician + Vita Easyshade Advance device + 3Shape Trios device	1) Visual assessment by dentists using the Vita 3D-Master; 2) Visual assessment by dental technicians using the Vita 3D-Mas- ter; 3) 3Shape Trios device; 4) Vita Easyshade device; 5) Vita Easyshade Advance device; 6) SpectroShade device 7) Spectro- Shade Micro device.
Area of color determination	Middle third of the buccal surface	Medially on the vestibular area	Cervical third, middle third and incisal third of the buccal surface.
Investigators	2 dentists: 1 male and 1 female→ visual assessment 2 dentists: 1 male and 1 female→ measurements with TRIOS Pod Color-P13 and MHT SpectroShadeTM 2 dentists→validating results	+ a dentist woman with 3 years + a dental technician woman with 18 years experience	+ 2 experienced dentists + 2 experienced dental technicians
Recorded measurements	3D-Master values	3D-Master values L*a*b* ΔE	3D-Master values L*a*b* ΔE
Assessed parameters	Interexaminer reliability (reproducibility) Validity	Accuracy Repeatability Clinical acceptance	Accuracy Repeatability Clinical acceptance
Results	- Reliability of computer-based systems higher than the subject, visual method. - Best agreement for the color value demonstrated by MHT SpectroShadeTM, - 3Shape Trios® Color : best agreement for the color chroma and hue.	Accuracy in comparison to VITA Easyshade Advance 4.0: *43.9% for the Trios®Color scanner, *35.5% for the visual colour determination by the dentist *34.6% for the visual colour determination by the dental technician. Repeatability: *VITA Easyshade :76.6% *Trios®Color: 78.3%.	- No significant difference between The Trios and the digital instruments tested in this study with respect to the repeatability of color shade measurement. - In terms of accuracy, significant best behavior for SpectroShade Micro and no difference between the intraoral 3D scanning device and other digital systems and the visual group consisting of dentists and dental technicians. - Analyzing the CIE Lab values and the ΔE values, clinically relevant differences negligible between dentists, dental technicians, and the intraoral scanning device are.
Conclusion	The effectiveness of the Trios Color was as good as the validated digital colorimetric system and as the conventional, visual method for color determination of teeth.	The Trios®Color intra-oral scanner appears to be a good alternative to the current standard of visual tooth colour determination. The colour determination module attains better results than visual colour determination and is comparable to the reference instrument VITA Easyshade. However, further measures are necessary to optimise tooth colour determination.	The results demonstrate the possibility of using intraoral 3D scanning systems for the measurement of tooth colors.

Table 2: Methodological characteristics and outcomes of the included studies.

Accuracy

In the study by Brandt et al. [9], the accuracy was defined as agreement in percent between the 3D Master values of three color determination methods (visual assessment by a dentist, visual assessment by a dental technician and use of the TRIOS color) in comparison to the reference instrument VITA Easyshade Advance 4.0. The measuring accuracy was:

- 43.9% for the Trios®Color scanner,
- 35.5% for the visual colour determination by the dentist,
- and 34.6% for the visual colour determination by the dental technician.

Concerning the L, C and h values, significant differences were discernible from the comparison of all three methods with the VITA Easyshade in respect to chroma (C) and hue values (h). The lightness values (L) revealed good correspondence.

Mehl et al. [13] determined 'relative accuracy' given that determining accuracy in terms of trueness was not possible because the true shades of the teeth in the study were unknown. The shade found most often by all the methods compared in the study (majority shade) was considered close to the true shade. Doing so allowed the authors to count the number of times methods agreed with the majority shade, thereby providing a measure for 'relative accuracy.' The results of the study were as follows:

- 3Shape: 61,2%

- Vita Easyshade advance: 59,2%
- Spectroshade: 57,4%
- Spectroshade Micro: 73,3%.
- Visual assessment combining data of dentists and dental technicians: 49,5%.

There was a significant difference in the SpectroShade Micro method compared to the others. This proves that this method offers the best accuracy.

Also, for Gotfredsen et al. [8], the accuracy of the color determination needed to be quantified indirectly. The authors used a different protocol from other studies. They compared measurements of objective methods (MHT SpectroshadeTM and Trios®Color scanner) with those of visual, subjective method made by two dentists. Two others dentists validated results by comparing two measurements for each tooth. The shade, color tap in the Vita 3D-Master system for each selected method were chosen and placed beside the assessed tooth. The question: "Which shade tap is the best match" was answered and registered for each of the two validating dentist. For each comparison the method yielding the best match was marked and given the score 1. If all methods were equally good, they should have the same number of best matches. If one method was better than the other method, the number of best-match would exceed the average. In the situation where two methods have yielded the same shade, there was no need to perform the visual comparison. The two methods then shared the mark, which means it counted as 0.5 for each. The validity of the measurements was evaluated by calculating the frequency of best-match for each method. No significant difference was found between Trios® Color and the conventional, visual method and between the MHT SpectroShadeTM and the conventional, visual method. The validity was around 50%.

Repeatability

Two studies reported data on repeatability [9,13]. In the study by Brandt et al. [9], measurements were repeated three times with the intra-oral scanner and VITA Easyshade in the case of 20 test subjects. The repeatability of the VITA Easyshade advance system was 76.6% overall, while that of the Trios® Color scanner was 78,3%.

Mehl et al. [13] assessed repeatability of four spectrophotometers (Vita Easy- shade, Vita Easyshade Advance, SpectroShade and Spectro- Shade Micro) and of the Trios® Color scanner. Three sites of the buccal surface were integrated into the calculation, which resulted in 2040 3D-Master shade values. Repeatability of the digital devices was as follows:

- 3Shape: 66,7%
- Vita Easyshade advance: 68,3%
- Spectroshade: 61,7%
- Spectroshade Micro: 71,7%.

Reproducibility

Reproducibility of color mesurements was assessed in only one study [8], and was described by the term reliability.

The reliability of the 3Shape Trios® Color and MHT SpectroShadeTM was performed as an interexaminer, pre-study including two measurements with each of the two devices on 24 natural teeth performed by two dentists. The same two dentists evaluated 63 teeth with by subjective, visual shade determination using the same VITA 3D-master guide as used for the objective methods.

It was concluded that the reproducibility of the objective, computer-based systems was high compared with the subjective, visual method for color determination. The MHT SpectroShadeTM demonstrated the best agreement for the color value (unweighted Kappa value = 0,73), whereas the 3Shape Trios® Color had the best agreement of all included methods for the color chroma and hue (0,71 and 0,74 respectively).

Clinical acceptance

In the study by Brandt et al. [9], when considering the colour differences in relation to the clinical acceptance, however, only 21.5% of the measurements with the Trios®Color scanner, 26.2% for the visual colour determination by the dentist and 27.1% for the visual colour determination by the dental technician are outside the tolerance range (ΔE = 6.8).

Mehl et al. [13] compared the ΔE between seven groups and found clusters of measurement methods with very similar outcomes: 1) Dentist, Technician, and 3 Shape; 2) SpectroShade and SpectroShade Micro; and 3) Easyshade and Easyshade Advance. The differences in Easyshade and Easyshade Advance compared to the other devices were significant. By contrast, no statistical differences were seen between the visual groups and the digital groups 3Shape, SpectroShade, and SpectroShade Micro.

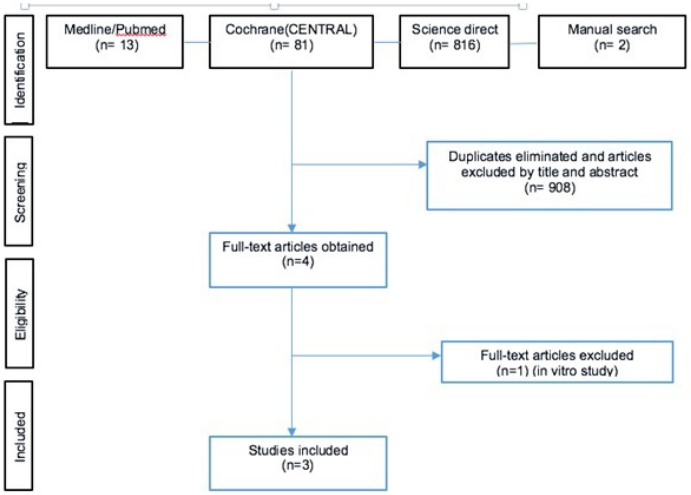

Figure 1: Flow chart of article selection.

Discussion

The aim of this systematic review was to assess the accuracy, repeatability and reproducibility of digital intraoral scanner for shade selection and to verify whether it can be a good alternative

to the current standard of visual tooth colour determination and to other devices. During analyse of the literature, we faced some limitations such as:

- The small number of studies published regarding the shade selection by intraoral scanner, although verification of accuracy and reliability should be a prerequisite for the clinical application of any new technology.
- All of these studies were conducted on the same device, the Trios®Color scanner even if other devices from other firms have been introduced on the market.
- The heterogeneity regarding the protocols of studies (teeth, area, device used, investigators…).
- The heterogeneity concerning the results of studies.

Accuracy of the Trios color was respectively 43,9%, 50% and 61,2% in the studies by Brandt et al. [9], Gotfredsen et al. [8] and Mehl et al. [13]. The scanner initially appears to attain a disappointing result in the study by Brandt. However, it is superior to the visual colour determination by both dentists and dental technicians.

Difference in the results is due to differences in study protocols and comparison reference system.

VITA Easyshade system was chosen as a reference for the method comparison in the study by Brandt [9] due to its high measuring accuracy of 92.6% and 83,3% evaluated repectively in the in vitro study by Kim-pusateri et al. [14] and in vivo study by Paul et al. [3]. These high values were not confirmed in the study by Mehl et al. [13] wich found an accuracy of 59,2% for the Easyshade device and 61,2% for the Trios color. The latter study assessed the accuracy of different spectrophotometers and of the visual method in addition to that of the Trios color and concluded that the intraoral 3D scanner does not differ significantly from all the other groups and that the Spectroshade Micro offers the best accuracy. Similar results have been presented in other study by Khurana et al., in which spectroShade Micro (at 82.7%) also provided the highest proportion of complete agreement. Easyshade and X-Rite ShadeVision scored 50% and 59.7%, respectively [15]. Thus, different devices cannot be used to fabricate restorations with predictable color quality because of poor interdevice reliability [6]. Another study also suggested that these devices should not be used interchangeably [16].

Concerning repeatability, the Trios color scored 78,3% [9] and 66,7% [13]. These results are comparable to those of Vita Easyshade: 76,6% and 68,3% measured repectively in the studies of Brandt et al. [9] and Mehl et al. [13]. Repeatability is good but not perfect despite the use of the newest generations of up-to-date digital measurement systems. This could be explained by the fact that layered structure of a tooth consisting of enamel, dentin, cement, and pulp, behaves differently when absorbing or reflecting different types of light, thus increasing the difficulty of shade matching [16]. Another reason for measurement uncertainty is that the output in the 3D-Master scale is discrete. The true shade may lie about halfway between two colors. Then, neither of the two shades captures the true shade correctly, and both are more or less equally close. The apparatus needs to select one of them; hence, the only thing it can do is to select the one that is marginally better than the other. As there is always measurement noise, it will sometimes arbitrarily capture one color at one time, and another color at other times [13].

Additionnally, to evaluate the accuracy and the repeatability of color detecting instruments, the same measuring position and surrounding conditions are important [5]. Most studies use templates for the exact replacement of the probe tip [10,17], which were not used in the studies of the review to comply with the clinical situation.

The repeatability of shade measurement could also be affected by different tooth areas [18]. Natural teeth are small, multilayered, and curved, exhibiting color transitions in many directions [5]. Therefore, based on a previous study, the incisal area with translucency frequently was affected by the background, and the cervical area was also influenced by the scattered light from the gingival area [19]. The middle third region of the labial tooth surface showed the most consistent results [18]. To reduce influencing variables and select the best representative site for color determination [20], the measurement was performed only on the labial surface, middle third of the tooth, or scanned images in the study of Brandt et al. [9]. Contrariwise, color measurements were performed for each tooth on the cervical third, middle third (central part), and incisal third of the buccal surface. This fact could explain result differences between the two studies.

However, there is no standard scanning method for color detection with a digital scanner. During scanning in clinical practice, it may be hard to control variables such as scan angle, scan distance, light source, shadow of surrounding tissue, operator's experience, and data overwrite due to redundant scanning [7].

Within the limitations of this study, color measurements obtained with digital intraoral scanners and computer-assisted image analysis were in accordance with those of the validated digital systems and the conventionnal, visual method. Therefore, it appears that it is possible to use the Trios color for shade selection without requiring additionnal conventionnal method. However, due to the scarce well-documented scientific evidence, there is an urgent need for more studies.

References

1. Alomari M, Chadwick RG. Factors infuencing the shade matching performance of dentists and dental technicians when using two different shade guides. British Dental Journal. 2011; 211: E 23.
2. Igiel C, Weyhrauch M, wentaschek S, et al. Dental color matching: A comparison between visual and instrumental methods. Dental Materials Journal. 2016; 35: 63-69.
3. Paul S, Peter A, Pietrobon N, et al. Visual and spectrophotometric shade analysis of human teeth. J Dent Res. 2002; 81: 578-582.

4. Carsten DL. Successful shade matching--what does it take?. Compend Contin Educ Dent. 2003; 24: 175-178.
5. Chu SJ, Trushkowsky RD, Paravina RD. Dental color matching instruments and systems. Review of clinical and research aspects. J Dent. 2010; 38: 2-16.
6. Dozic A, Kleverlaan CJ, El-Zohairy A, et al. Performance of five commercially available tooth color-measuring devices. J Prosthodont. 2007; 16: 93-100.
7. Goracci C, Franchi L, Vichi A, et al. Accuracy, reliability, and efficiency of intraoral scanners for full-arch impressions : a systematic review of the clinical evidence. European Journal of Orthodontics. 2016; 38: 422-428.
8. Gotfredsen K, Gram M, Ben Brahem E, et al. Effectiveness of Shade Measurements Using a Scanning and Computer Software System: a Pilot Study. Int J Oral Dent Health. 2015; 1: 2.
9. Brandt J, Nelson S, Lauer HC, et al. In vivo study for tooth colour determination-visual versus digital. Clin Oral Investig. 2017; 21: 2863-2871.
10. Johnston WM. Color measurement in dentistry. J Dent. 2009; 37: e 2-6.
11. Roberts CT, Richmond S. The design and analysis of reliability studies for the use of epidemiological and audit indices in orthodontics. British Journal of Orthodontics. 1997; 24: 139-147.
12. Naidu D, Freer TJ. Validity, reliability, and reproducibility of the iOC intraoral scanner: a comparison of tooth widths and Bolton ratios. American Journal of Orthodontics and Dentofacial Orthopedics. 2013; 144: 304-310.
13. Mehl A, Bosch G, Fischer C, et al. In vivo tooth-color measurement with a new 3D intraoral scanning system in comparison to conventional digital and visual color determination methods. International Journal of Computerized Dentistry. 2017; 20: 343-361.
14. Kim-Pusateri S, Brewer JD, Davis EL, et al. Reliability and accuracy of four dental shade-matching devices. J Prosthet Dent. 2009; 101: 193-199.
15. Khurana R, Tredwin CJ, Weisbloom M, et al. A clinical evaluation of the individual repeatability of three commercially available color measuring devices. Br Dent J. 2007; 203: 675-680.
16. Sarafianou A, Kamposiora P, Papavasiliou G, et al. Matching repeatability and interdevice agreement of 2 intraoral spectrophotom- eters. J Prosthet Dent. 2012; 107: 178-185.
17. Olms C, Setz JM. The repeatability of digital shade measurement, a clinical study. Clin Oral Investig. 2013; 17:1161-1166.
18. Karamouzos A, Papadopoulos MA, Kolokithas G, et al. Precision of in vivo spectrophotometric colour evaluation of natural teeth. J Oral Rehabil. 2007; 34: 613-621.
19. O'Brien WJ, Hemmendinger H, Boenke KM, et al. Color distribution of three regions of extracted human teeth. Dent Mater. 1997; 13:179-185.
20. 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.