

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/45150225>

Dental color matching instruments and systems. Review of clinical and research aspects

Article in *Journal of dentistry* · December 2010

DOI: 10.1016/j.jdent.2010.07.001 · Source: PubMed

CITATIONS

190

READS

1,991

3 authors:



Stephen J Chu

New York University College of Dentistry

83 PUBLICATIONS 926 CITATIONS

[SEE PROFILE](#)



Richard Trushkowsky

New York University College of Dentistry

72 PUBLICATIONS 526 CITATIONS

[SEE PROFILE](#)



Rade Paravina

University of Texas Health Science Center at Houston

108 PUBLICATIONS 1,951 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



Color in Dentistry: A Clinical Guide to Predictable Esthetics, Quintessence Publishing [View project](#)

available at www.sciencedirect.comjournal homepage: www.intl.elsevierhealth.com/journals/jden

Review

Dental color matching instruments and systems. Review of clinical and research aspects

Stephen J. Chu^a, Richard D. Trushkowsky^{b,*}, Rade D. Paravina^c

^a Department of Periodontology and Implant Dentistry, New York University College of Dentistry, New York, NY, United States

^b Department of Cariology and Comprehensive Care, New York University College of Dentistry, 345 East 24th Street, New York, NY 10010, United States

^c Department of Restorative Dentistry and Biomaterials, University of Texas Dental Branch at Houston, Houston, TX, United States

ARTICLE INFO

Article history:

Received 8 May 2010

Received in revised form

23 June 2010

Accepted 2 July 2010

Keywords:

Tooth

Teeth

Color

Color measurement

Colorimeters

Spectrophotometers

Digital camera

ABSTRACT

Objectives: To review current status of hand held systems for tooth color matching in vivo and corresponding research.

Sources: “Medline” database from 1981 to 2010 were searched electronically with key words tooth, teeth, color and dentistry.

Conclusion: Spectrophotometers, colorimeters and imaging systems are useful and relevant tools for tooth color measurement and analysis, and for quality control of color reproduction. Different measurement devices either measure the complete tooth surface providing a “color map” or an “average” color of the limited area [3–5 mm] on the tooth surface. These instruments are useful tools in color analysis for direct or indirect restorations, communication for indirect restorations, reproduction and verification of shade. Whenever possible, both instrumental and visual color matching method should be used, as they complement each other and can lead towards predictable esthetic outcome.

© 2010 Elsevier Ltd. All rights reserved.

1. Introduction

The interest in color research in dentistry has increased significantly over the past several decades. When keywords color and dentistry were used for Medline search, only 107 papers were found by 1970. In subsequent decades, the number of references increased as follows: 409 (1980), 1134 (1990), 2259 (2000) and 4062 (April 2010). Advancements in technology, computers, the Internet, and communication systems have greatly affected and shaped modern society. Commensurate with these strides are the advancements in contemporary dentistry. During the past half decade, the

dental profession has experienced the growth of a new generation of technologies devoted to the analysis, communication and verification of shade. Shade determination for direct and indirect restorations has always been a challenge for the esthetic dentist. Clark in 1931 described this in the Color Problems in Dentistry.¹ As opposed to subjective visual shade selection with not always quite controlled conditions and methods, and shade guides that exhibited significant shortcomings, several authors tried to objectively quantify tooth color in the past. This was done through identifying color problems in dentistry²; the importance of the quantity and quality of light required to properly analyse shade³

* Corresponding author. Tel.: +1 718 948 5808; fax: +1 718 948 4453.

E-mail address: rt587@nyu.edu (R.D. Trushkowsky).

0300-5712/\$ – see front matter © 2010 Elsevier Ltd. All rights reserved.

doi:10.1016/j.jdent.2010.07.001

through studying correlation between extracted teeth and shade guides⁴ or the development of the early shade measuring instruments and shade guides.⁵

The late 1990s marked the birth of a new industry in dentistry, commercially available instrument-based color measurement systems, with the development of the ShadeScan system (Cortex Machina, Montreal, Canada).⁶ This was the first effort toward a shade analysis system for complete tooth surface measurement. Prior literature published by several authors described limited area measurement instruments, with an optical diameter of 3–5 mm, in the analysis of shade.^{7–9} Another study evaluated clinical application of the ShadeScan prototype which employed digital camera technology, in a case report comparing visual vs. instrument-based shade information in the restoration of a single maxillary central incisor.¹⁰

Today's shade-matching technologies have been developed in an effort to increase the success of color matching, communication, reproduction and verification in clinical dentistry, and, ultimately, to increase the efficiency of esthetic restorative work within any practice. The aim of this paper is to provide a comprehensive review of the current state of shade-matching technologies and instrumentation, and their clinical and research application.

2. Rationale

Dental shade-matching instruments have been brought to market to reduce or overcome imperfections and inconsistencies of traditional shade matching. The most commonly used shade-matching method is the visual method, whilst Vitapan Classical (Vita Zahnfabrik, Bad Säckingen, Germany) and its derivations are probably the most commonly used shade guides. The colored tabs of distinctive shades organize the empiric-based Vita chart.^{11–14} In addition, unequivocal findings were reported on color consistency amongst shade guides from the same manufacturer.^{15,16} Introduction of evidence-based Vitapan 3D-Master shade guides, Toothguide, Bleachedguide and particularly Linearguide by the same manufacturer correspond to color of human teeth and therefore increase chances for successful shade matching.^{17,18}

Historically, assessing shade visually has been characterized by several innate difficulties: metamerism, suboptimal color matching conditions, tools and method as well as the receiver's age fatigue, mood and drugs/medications.¹⁹ Despite these difficulties, the human eye can discern very small

differences in color. However, the ability to communicate the degree and nature of these differences is lacking.

The final color of an all-ceramic restoration is a merging of the underlying tooth structure or core and the ceramic material. The color of the final restoration cannot match the shade selected from a shade guide unless this modification is taken into account. Therefore, a stump or base tooth preparation shade needs to be obtained and transmitted to the technician.²⁰

3. Overview

Instruments for clinical shade-matching encompass spectrophotometers, colorimeters and imaging systems. As with any device, benefits and limitations exist, and the clinician must consider how the technology relates to expectations and needs. Intra-oral color measuring devices have been designed to primarily fit the needs of clinical dentistry, such as information on the corresponding shade tabs, tooth translucency, or information associated with color communication, reproduction and verification. This, together with price limitation dictated by the dental market, resulted in having scientific aspects, such as providing reflectance values or color formulation, less emphasized. Another significant difference compared to other, non-dental applications, are optical properties of human teeth—they are small, curved, multi-layered, translucent and exhibit color transitions in all directions (gingival to incisal, mesial to distal and labial to lingual). This is why the accurate repositioning (measurement of the same area) is frequently of critical importance for either clinical and research use of dental color matching devices. The list of instruments and software for in vivo color matching and their properties is given in Table 1.²¹

In addition to the instruments listed in Table 1, there are numerous dental color matching products that are presently withdrawn from the market, of limited availability, or undergoing major redesigning. The list includes Chromascan (Sterngold, Stamford, CT, USA), Dental Color Analyzer (Wolf Industries, Vancouver, Canada), Identacolor II (Identa, Holbaek, Denmark), Digital Shade Guide DSG4 (A. Reith, Schorn-dorf, Germany), Ikam (Metalor Technologies, Attleboro, MA, USA), ShadeEye NCC Chroma Meter (Shofu Dental, Menlo Park, CA, USA), Beyond Insight Shade Taking Device (Beyond Dental & Health, Beijing, China), Shadescan (Cynovad, Montreal, Canada) and Vita Easyshade (Vita Zahnfabrik, Bad Säckingen, Germany).

Table 1 – Instruments and software for color matching in dentistry: types, measurement area and relative cost (\$1000–\$7500).²¹

Product	Manufacturer	Device type	Measurement area	Relative cost
ClearMatch	Clarity Dental, Salt Lake City, UT	Software, digital image analysis	Complete tooth image	Low
CrystalEye	Olympus America, Center Valley, PA	Imaging Spectrophotometer	Complete tooth image	High
Easyshade Compact	Vident, Brea, CA	Spectrophotometer	5-mm probe diameter	Low
Shade-X	X-Rite, Grandville, MI	Spectrophotometer	3-mm probe diameter	Low
ShadeVision	X-Rite, Grandville, MI	Imaging colorimeter	Complete tooth image	Moderate
SpectroShade Micro	MHT, Niederhasli, Switzerland	Imaging Spectrophotometer	Complete tooth image	Moderate

4. Characteristics and clinical application

4.1. Spectrophotometers

Spectrophotometers are amongst the most accurate, useful and flexible instruments for overall color matching and color matching in dentistry.²² They measure the amount of light energy reflected from an object at 1–25 nm intervals along the visible spectrum.^{23,24} A spectrophotometer contains a source of optical radiation, a means of dispersing light, an optical system for measuring, a detector and a means of converting light obtained to a signal that can be analysed. The data obtained from spectrophotometers must be manipulated and translated into a form useful for dental professionals. The measurements obtained by the instruments are frequently keyed to dental shade guides and converted to shade tab equivalent.²⁵ Compared with observations by the human eye, or conventional techniques, it was found that spectrophotometers offered a 33% increase in accuracy and a more objective match in 93.3% of cases.²⁶

Crystaleye (Olympus, Tokyo, Japan) combines the benefits of a traditional spectrophotometer with digital photography. Through the development of optical and image processing technology, this product allows the practitioner to match tooth shade and color more accurately and simply compared with the traditional spectrophotometer.²⁷

The significant benefit of this system is that ‘virtual shade tabs’ in the computers database can be cross-referenced and superimposed visually onto the natural tooth image to be matched giving the technician the ability to visualize the correct shade tabs. The digital image produced by the Crystaleye uses a 7-band LED light source, which results in a more precise depiction of color than the conventional systems used with digital cameras. Moreover, the image produced by the Crystaleye is taken from inside the oral cavity and consequently is devoid of the external light that can cause discrepancies.

Vita Easyshade Compact (Vita Zahnfabrik, Bad Säckingen, Germany) is cordless, small, portable, cost efficient, battery operated, contact-type spectrophotometer that provides enough shade information to help aid in the color analysis process. Different measurement modes are possible with Easyshade Compact: tooth single mode, tooth area mode (cervical, middle and incisal shades), restoration color verification (includes lightness, chroma and hue comparison) and shade tab mode (practice/training mode).²⁸

Shade-X (X-Rite, Grandville, MI) is also compact and cordless “spot” measurement” spectrophotometer with 3-mm probe diameter, and keyed to the majority of popular shade guides. Shade-X have two databases to match the color of the dentin (more opaque) and the incisal tooth regions (more translucent).²⁹

SpectroShade Micro (MHT Optic Research, Niederhasli, Switzerland) is an imaging spectrophotometer. It uses a digital camera/LED spectrophotometer combination. It has an internal computer with the analytical software. The tooth positioning guidance system, shown on the LCD touch screen, is used during color measurement. Images and spectral data can be saved on the internal memory and transferred to a computer.³⁰

4.2. Colorimeters

Colorimeters measure tristimulus values and filter light in red, green and blue areas of the visible spectrum. Colorimeters are not registering spectral reflectance and can be less accurate than spectrophotometers (aging of the filters can additionally affect accuracy).³¹ ShadeVision (X-Rite, Grandville, MI) is an imaging colorimeter. Complete tooth image is provided through the use of three separate databases: for gingival, middle and incisal third. Virtual try-in feature enables virtual testing of color reproduction during fabrication.³²

4.3. Digital cameras and imaging systems

Digital Cameras. Most consumer video or digital still cameras acquire red, green and blue image information that is utilized to create a color image. The RGB color model is an additive model in which red, green and blue light are added together in various ways to reproduce a broad array of colors. Digital cameras represent the most basic approach to electronic shade taking, still requiring a certain degree of subjective shade selection with the human eye.³³ Various approaches have been used to translate this data into useful dental color information.

ClearMatch (Smart Technology, Hood River, OR) is a software system that uses high-resolution digital images and compares shades over the entire tooth with known reference shades.³⁰ Similar to the software associated with color measuring devices, ClearMatch contains the color database of industry-standard shade guides.³⁴

4.4. Interpretation and application of shade analysis data

Complete tooth surface measurement [CTSM] devices give a color map of the gingival, body and incisal shades for the fabrication of direct or indirect restorations. These systems give a virtual shade overlay of the proposed tab onto the digital image on the computer screen of the tooth measured for visual reference and assessment by the clinician and/or technician. CTSM spectrophotometers, such as Crystaleye and Spectro-Shade, provide shade tab designation and the respective ΔE^* values compared to shade tab values in the memory. However, these mappings are two dimensional and they do not necessarily take into account the shape, texture, thickness of the restoration, type of abutment and different core material (metal or ceramic).³⁵ In addition, they ‘average out’ color data over the complete tooth surface or larger defined areas which can lead to inaccurate shade information.

Limited area measurement devices provide 3–5 mm diameter areas of the tooth being measured. Therefore several areas of the tooth should be considered to obtain a representative evaluation of tooth shade. At a minimum, a limited area measurement of the gingival, body and incisal areas of the tooth [total of 3 measurements] should be assessed and recorded for the technician if an indirect restoration is prescribed. It was found that decreasing the window size when examining extracted teeth with a spectrophotometer and spectroradiometer resulted in lower CIE $L^*a^*b^*$ values.³⁶ Small-window tooth color measurement may cause edge loss of the light due to a tooth’s translucency.³⁷

Once the technology-based information is analysed, the information must be communicated to the technician for indirect restorations.³⁸ The aforementioned instruments and technologies are predominantly intended for shade analysis, however, this information alone may be insufficient for the technician to adequately interpret the shade information provided. Subsequent reference photography is highly recommended for communication on tooth color. Digital photographs are an important adjunct to the laboratory technician and together with the shade or “color map” should be sufficient communication material to construct an acceptable restoration.

Clinicians and technicians are frequently located in different areas. A digital camera permits the transfer of images from the clinician to the technician. The best way to reference shade information is by using shade tabs to communicate shade.³⁹ A systematic protocol to referencing shade information as well as changes in shade between tabs is required. Shades identified in the digital map are arranged by gingival (G), middle (M) and incisal third (I). The shade tabs should be selected and photographs should be taken with each tab in its proper orientation in reference to the tooth.

Camera and light settings and image format must be kept constant at all times for consistent shade color communication. In addition to the three basic shade tabs representing the respective G, M and I shades, two additional reference shade tab photographs should be included to graduate and calibrate shifts in hue, chroma and value between physical tabs visually in the laboratory, in the photographs and between the photos. One selected tab should be lighter in shade and one darker in shade in respect to the selected basic shades. The combination of accurate digital shade analysis information coupled with standardized reference shade communication photography can ensure a predictable esthetic restorative outcome of the final direct or indirect restoration.

Indirect restorations can and should be verified visually and with the instrument system in the laboratory prior to being returned to the clinician. This verification process can streamline wasteful chair side time attributed to remakes due to incorrect shade.^{40,41} Clinical excellence backed with sound color science and its appropriate interpretation can probably make the critical difference between good to excellent.⁴² Examples of color matching, interpretation and application of shade analysis data are given in Figs. 1–6.

5. Research

Besides the clinical applications, dental color measuring instruments and systems are increasingly used in research. The most frequent research topics associated with these instruments and systems are associated with evaluation of measurement uncertainties, comparison between visual and instrumental findings, visual color thresholds and evaluation on color compatibility, stability and interactions of human hard and soft oral tissues, head and neck tissues and dental materials. Although non-dental, professional bench-top color measurement instruments were used in many research projects in dentistry, this paper will focus mainly on these conducted using hand held devices designed for dental application.

5.1. Measurement uncertainties

In color science, evaluation of measurement uncertainties of shade-matching instruments is performed through precision and accuracy testing. The uncertainties associated with precision are most frequently associated with random errors, whilst the uncertainties associated with accuracy usually originate from systematic errors. Precision is tested by evaluation of repeatability (same method, operator or instrument) and reproducibility (different method, operator and/or instrument). Based on time interval, we are talking about short term (measurements in succession), medium term (hours) and long term measurements (weeks or longer). Based on the specimen manipulation, measurement can be performed with- and without replacement.⁴³ Evaluation of measurement uncertainties encompasses the use of referent instrument, preferably professional, non-dental, color measuring instrument.³⁷

In a study that compared five dental color measuring devices—ShadeScan, Easyshade, Ikam, IdentaColor II and ShadeEye, five group A Classical tabs were in vitro measured five times by two operators, whilst 25 upper right central incisors were measured in vivo by one operator. The best precision in vivo was recorded for Easyshade and Ikam, whilst performance of the other instruments was better in vitro than in vivo.¹² In an another study, SpectroShade, ShadeVision, VITA Easyshade and ShadeScan were evaluated.³¹ High reliability (reproducibility?) and variability in accuracy was reported. One in vitro study found that repeatability and accuracy of a dental color measuring instrument (ShadeScan) was influenced by shade guide systems used for testing.⁴⁴ When the precision of measurement of different tooth areas was evaluated, the middle third of each labial tooth surface exhibited the most consistent results.⁴⁵

Dental color matching instruments also provide the information on best matching tabs from different shade guides.^{25,46,47} This application-specific color information is also of importance and therefore requires proper attention of dental researches. When VITA EasyShade and ShadeEye NCC were tested on extracted human teeth, there were discrepancies in shade guide designations provided by the instruments. Higher inter-device agreement was recorded for Vitapan Classical than for Vitapan 3D-Master.²⁵

Digital imaging systems are becoming increasingly popular in determining the color of teeth. Precision and accuracy of these systems are influenced by the quality of camera and image processing method. Several studies reported that digital cameras, may be reliable instruments for determining the color of teeth and gingiva when combined with the appropriate calibration protocols.^{48–54}

Clinical imaging and conventional image processing methods such as Adobe Photoshop and Corel Photo-Paint are suitable for many purposes in dentistry: lab communication, documentation, patient education and others. However, scientific imaging,⁵⁵ appropriate methods of data processing and color science terminology is preferred in dental research. This, together with lack of the referent instrument (the instrument that has already been validated, not necessary by the same authors), diminished the validity of some studies on precision and accuracy of dental color matching instruments.

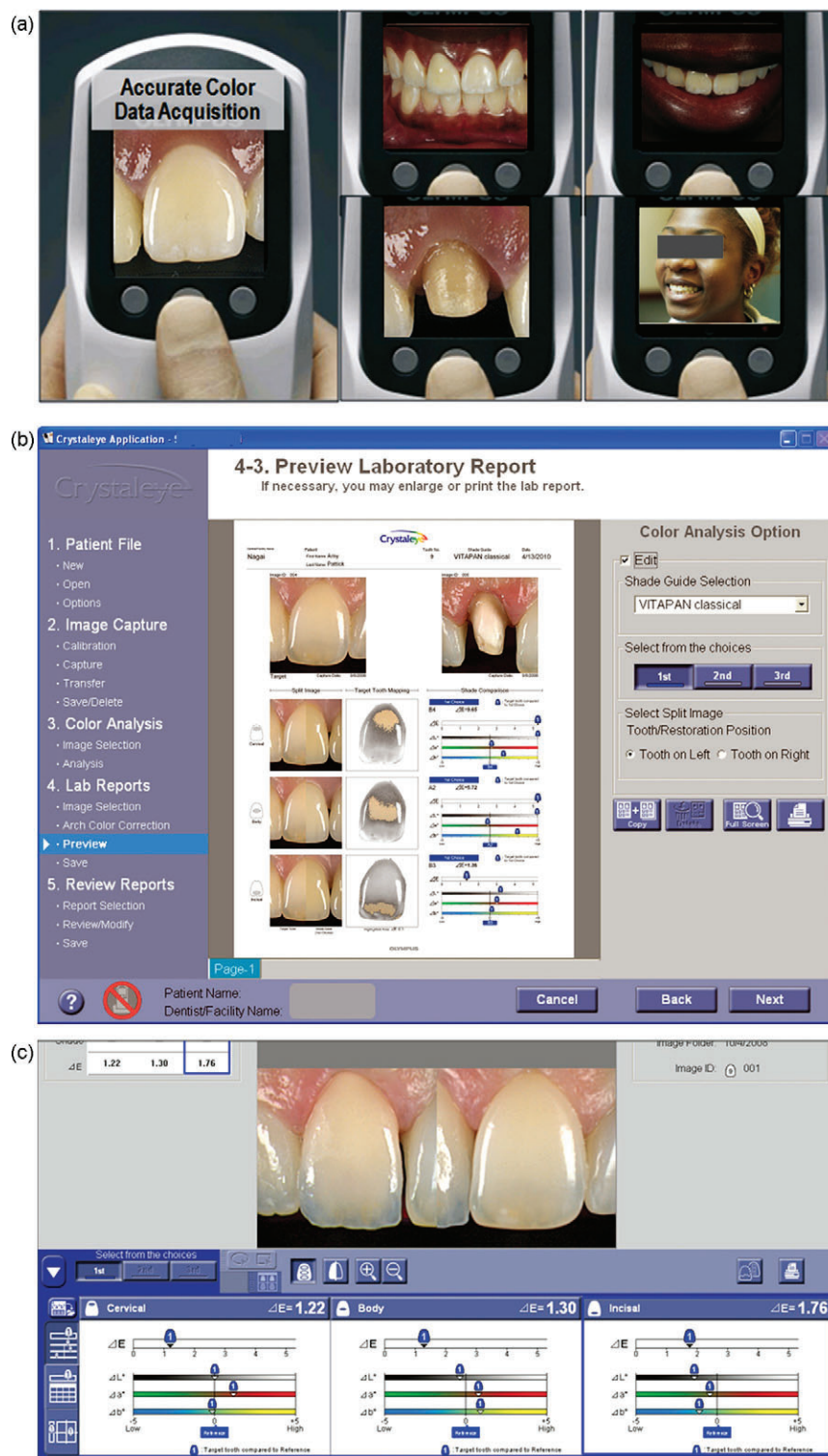


Fig. 1 – Clinical application of CrystalEye spectrophotometer (Courtesy Dr. Shigemi Nagai). (a) CrystalEye captures the spectral image of the tooth, abutment, arch and full face image. (b) Laboratory report can be sent to the lab as a quick color note. (c) Color analysis of the ceramic crown (after 1st bake try-in) placed on the abutment. Excellent color match was confirmed in the cervical and body areas. Minor modification may be required in the incisal area to increase the value and yellowness. (d) Color difference ΔE s obtained in all 3 areas are considered to be excellent color match. L^* value map indicates indistinguishable value distribution on #8 and #9.

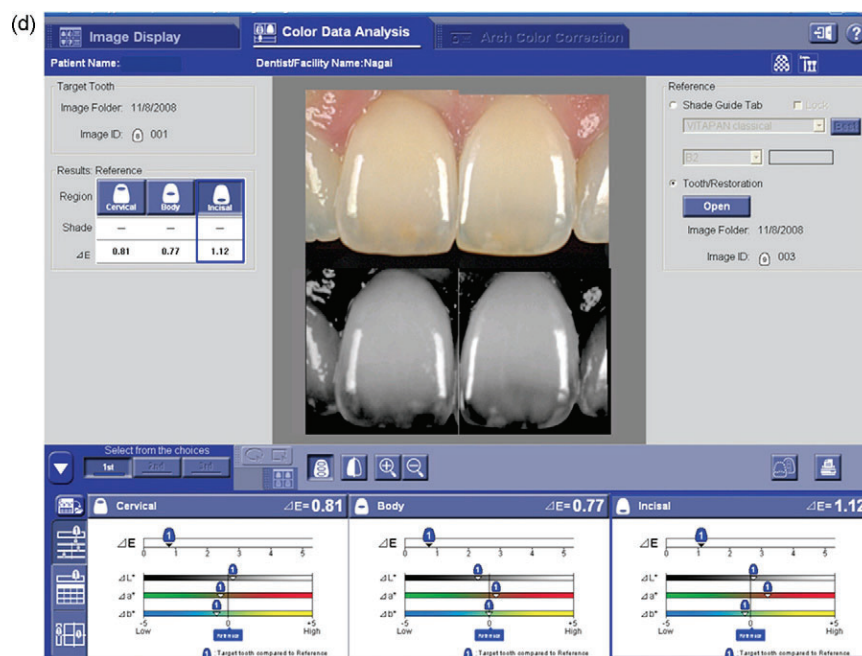


Fig. 1. (Continued).

5.2. Comparison between visual and instrumental findings

When the first dental color measuring instruments appeared, they exhibited slightly better accuracy compared to visual findings that were described as inconsistent.⁵⁶ Since that time, the modernization of both visual and instrumental means for color matching in dentistry occurred.^{17,57} More recently, better results were reported with dental spectrophotometer than using the visual method in approximately 47% of the cases,⁵⁸ which is in accordance with independent studies that documented the supremacy of spectrophotometric color matching compared to visual shade assessment.^{27,59} Another paper reported that the performance of Easyshade was comparable or better than that of dentists, whilst the agreement between visual and instrumental findings was qualified as good to very good.⁶⁰ In another paper, it was found that the agreement amongst the observer groups was significantly better than that of each device and that color matching instruments did not reflect human perception.⁶¹

It was found that consensus amongst observers led to better shade-matching results with some shade guides, compared to results of individual observers,⁶² and that intraexaminer shade-matching agreement was mainly acceptable.⁶³ Significantly higher visual-instrumental agreement was recorded for experienced dentists (compared to dental students and non-dental observers), regardless of shade guides and lighting conditions.⁶⁴

The comparison between visual and instrumental findings is a very attractive topic as it reveals pros and cons of both methods. Visual color matching is subjective and influenced by variety of factors. However, this method is not inferior and should not be underrated. Actually, the all “objective” color measuring instruments have been developed based on the

visual response of the “standard observer” and they are good only if they match that response. In addition, the numerically smallest ΔE^* value does not necessarily correspond to the best match because of the uneven eye sensitivity to hue, value and chroma differences. Therefore, the answer whether to use visual or instrumental method for color matching in dentistry is: whenever if possible, use both, as they complement each other and can lead towards predictable esthetic outcome.^{39–41}

5.3. Evaluation of visual color thresholds

Perceptibility and acceptability visual thresholds can be quantified only by combining visual and instrumental color measurement methods. Although majority of studies used professional (non-dental) color measuring devices in threshold evaluation, this topic is of exceptional importance in interpretation of color differences in clinical dentistry and dental research.

When the color difference between compared objects can be seen by 50% of observers (the other 50% will notice no difference), we are talking about the 50:50 perceptibility threshold.⁶⁵ When the color difference is considered acceptable 50% of observers (the other 50% would consider it unacceptable), this corresponds to 50:50 acceptability threshold. A color match in dentistry is a color difference at or below the former threshold, an acceptable color match is a color difference at or below the later one.⁶⁵

In dental literature, it is frequently interpreted that a ΔE^* of 1 is the 50:50 perceptibility threshold under controlled conditions (50% of observers will notice the color difference and 50% will see no difference between compared objects),⁶⁶ whereas a ΔE^* of 2.7⁶⁷ and 3.3⁶⁸ were found to be 50:50 acceptability thresholds (50% of observers will accept the restoration and 50% will replace it because of color mismatch).



Fig. 2 – Clinical application of EasyShade Compact spectrophotometer. (a) Instrument calibration. (b) Color measurement. (c) Color difference metric values as compared to the corresponding Vitapan Classical shade. (d) Color coordinate values and the corresponding Vitapan 3D-Master shade.

Several other studies, more or less controlled, reported the variability of findings on visual color thresholds.^{57,69–71} This, in addition to the introduction of new color difference formulae (CIEDE2000), suggests systematic approach and standardization of methods.

5.4. Color compatibility

Color compatibility studies encompass comparisons amongst teeth, shade guides and dental materials. Evaluation of color of natural teeth is important for clinical dentistry since knowledge on color ranges and color distribution of natural teeth can provide guidelines for designing of dental materials that will enable better and easier match to natural teeth.^{13,72} Databases encompassing spectral properties of teeth, regardless whether created using dental or non-dental color measuring devices, are of particular validity.⁷³ Two independent studies, both performed using Vita Easyshade, reported almost the same color coordinate ranges of natural teeth: $L^* = 55.5\text{--}89.6$ ⁷⁴ and $L^* = 58.7\text{--}88.7$ ⁷⁵; $a^* = 4.2\text{--}7.3$ ⁷⁴ and $a^* = 3.6\text{--}7.0$ ⁷⁵, and $b^* = 3.6\text{--}38.9$ ⁷⁴ and $b^* = 3.7\text{--}37.3$.⁷⁵ Current

shade guides exhibit moderate to pronounced discrepancy with results recorded for natural teeth. This discrepancy has been quantified by calculation of coverage error, the mean value of the minimal color differences amongst



Fig. 3 – Clinical application of Shade-X spectrophotometer.

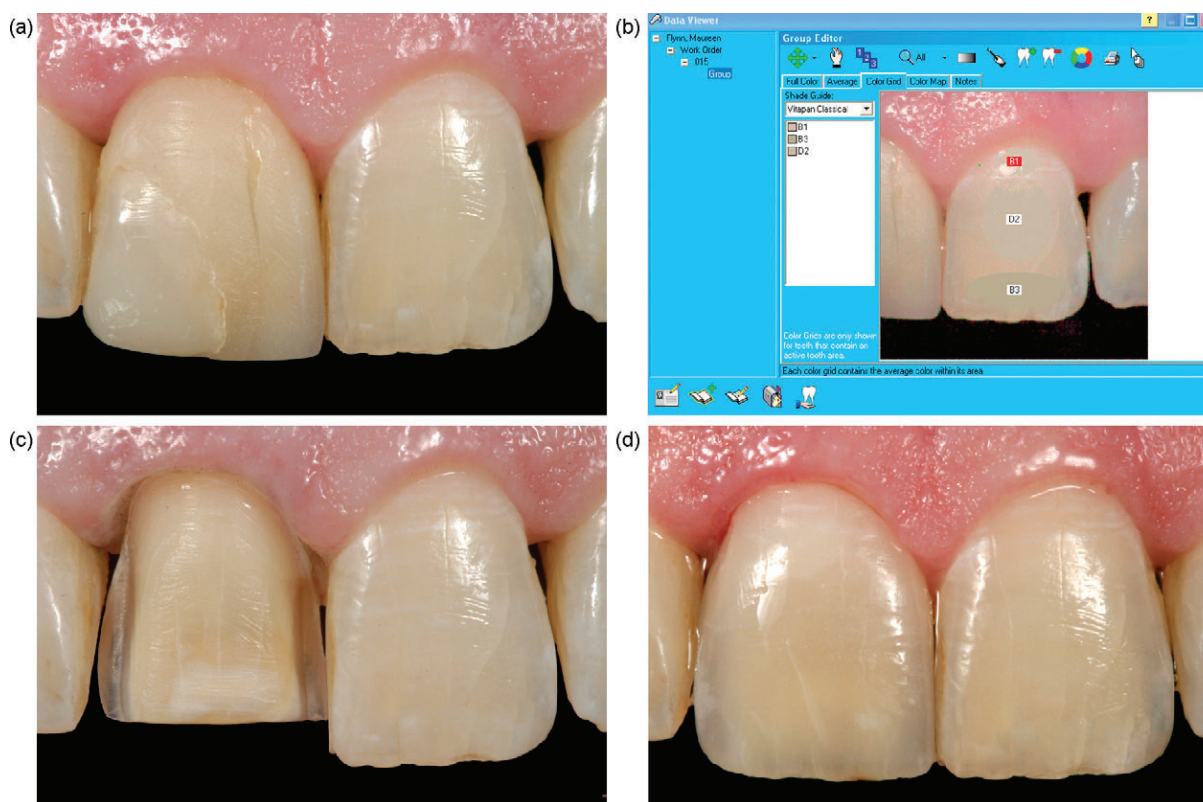


Fig. 4 – Clinical application of ShadeVision colorimeter. (a) The fractured veneer restoration on tooth #8 is to be replaced with a new veneer restoration. (b) The ShadeVision color mapping for tooth #9 to be matched with gingival, body and incisal shade reference tabs. (c) Veneer preparation tooth #8. It is important that an even thickness of tooth reduced is performed to insure color control of ceramic layering for predictable shade matching of the restoration. (d) Insertion of veneer restoration tooth #8 [Venus porcelain, Heraeus, Hanau, Germany] which matches the contralateral tooth satisfactorily and predictably without a remake.

each tab in the shade guide and the database of human teeth.^{17,73–76}

Although teeth exhibit color transitions in all directions, the correlation between colors of different regions on the labial tooth surface has been recorded. This study, performed using digital camera, suggested that color of a missing part of a tooth can be determined using the color of existing areas.⁷⁷ The same team reported color correlation between maxillary incisors and canines, which may influence color matching of missing teeth.⁷⁸

As far as the compatibility amongst materials is concerned, different comparisons have been performed. An Easyshade comparison between Vitapan Classical shade guide and four different veneering porcelain systems for metal ceramic restorations, revealed that differences were shade-dependent: A2 porcelain disks exhibited better match to corresponding VITA shade, followed by A3 and A3.5 disks.⁷⁹ The same instrument was used to test the ability of a ceramic system to correctly reproduce the shade selected using two shade guides. Toothguide 3D-Master outperformed VITA Classical.⁸⁰ When the quality of color match of different shade guides and corresponding porcelains was evaluated, the highest percentage of clinically acceptable matches was recorded for Toothguide 3-D Master/Omega 900 combination.⁸¹ A study, conducted using Easyshade,

reported that evaluated resin composites exhibited poor match compared to target Vitapan Classical tabs of the same shade designations.⁸² Similar conclusions were derived when various composites of corresponding shades were compared with a shade guide using a non-dental colorimeter,⁸³ and with each other using a bench-top spectrophotometer.⁸⁴

5.5. Color stability

Color stability of teeth and dental restoration is one of the prerequisites for long-lasting esthetics of dental restorations. Dental materials can exhibit color shifting during fabrication or at placement, and after placement. The later type of color shifting is associated with aging and staining.

When nanofill composite specimens were immersed into coffee, yerba mate, grape juice or water (control solution) for one week and tested using Easyshade, perceivable color change was observed only for the group immersed into the grape juice.⁸⁵ Another study used Easyshade to evaluate resin composites polished with two one-step polishing systems and exposed to coffee solution for seven days. Although all materials exhibited significant color changes, statistically significant polishing system-dependent differences were recorded ($p < 0.05$). Composite polymerized against Mylar

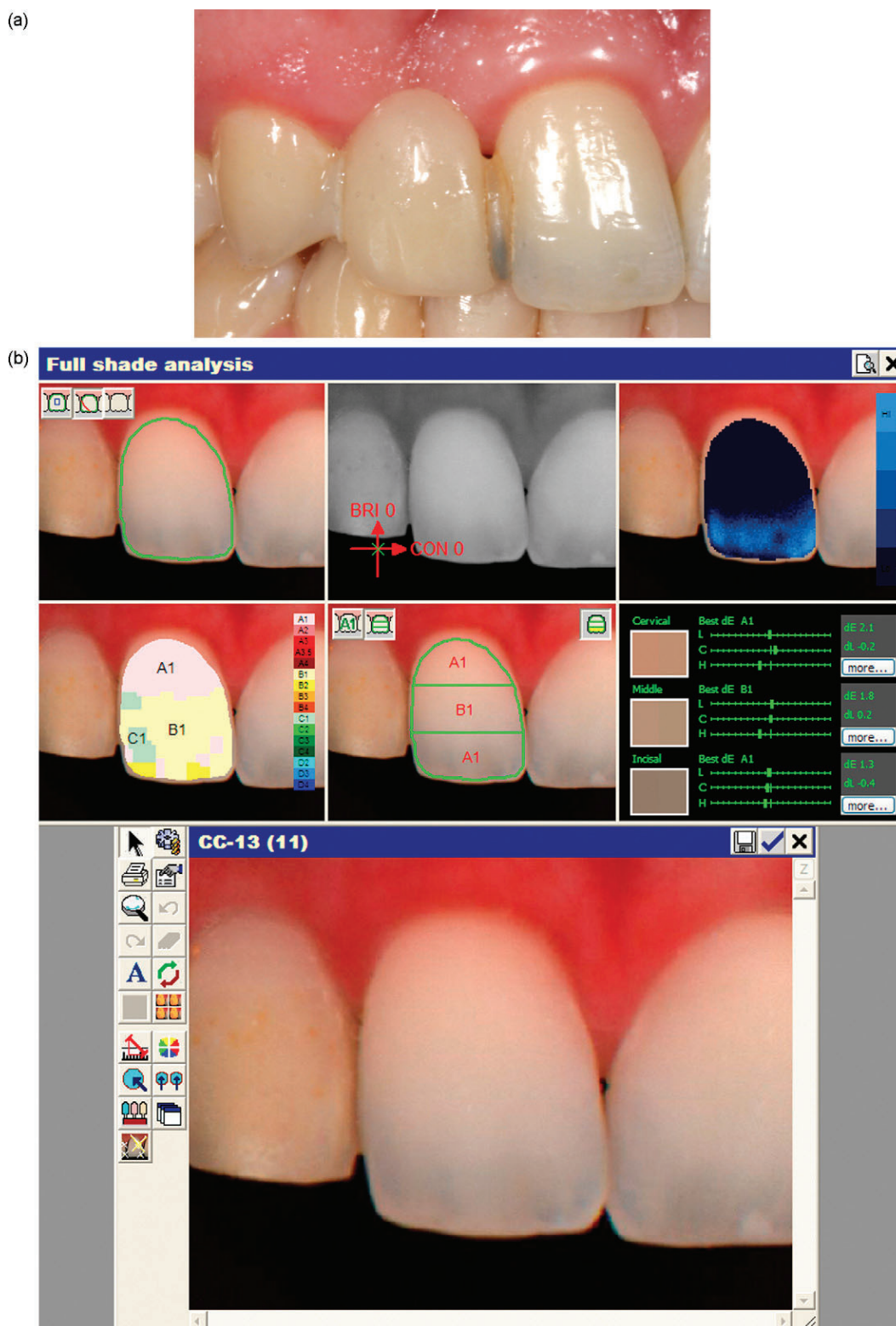


Fig. 5 – Clinical application SpectroShade Micro spectrophotometer. (a) Tooth #7 of a congenitally missing lateral incisor to be replaced with an implant [3i, Palm Beach, FL] and metal ceramic full coverage restoration. (b) The SpectroShade Micro system creates a color map which can be converted to several shade guide systems, this being the Classic Vita Shade Guide. It provides either an overall shade or the shade can be broken down into three distinct areas, cervical, middle and incisal, and provides detailed shade information in each of these areas and will provide a mathematical analysis resulting in a ΔE^* value. (c) Virtual shade verification can be formed with this system so that shades can be assured prior to time consuming patient visits. (d) Final restoration of tooth #7 with an implant and crown with an excellent aesthetic and functional outcome.



Fig. 6 – Technology-based systems provide shade tab information and then reference communication images are required by laboratory technicians to visualize the shade information. Gingival, body and incisal photographs should be submitted to the lab as a minimum requirement for shade reference.

number of firings (3, 5, 7, or 9) ($p < 0.001$) and the veneering porcelain shade ($p < 0.001$). Although the color of the specimens was influenced by repeated firings, recorded changes in color were clinically acceptable.⁸⁷ In another study by the same group, the effect of ceramic thickness and number of firings on the color of two all-ceramic systems was reported. The mean ΔE^* value increased as the thicknesses increased for both types of all-ceramic specimens tested. However, the difference between materials was significant.⁸⁸

Color stability of 3 veneering ceramics for zirconia frameworks was evaluated using SpectroShade. All materials exhibited significant color deviation from the reference teeth, with ΔE^* ranging from 5.6 to 6.8, but no significant differences were found between crowns and teeth for the 3 ceramics. The authors concluded that all 3 ceramics met the esthetic demands to a limited extent.⁸⁹ In an evaluation of a standard shade guide for color change after disinfection using Easyshade, a statistically significant increase in lightness and chroma were observed after 2 and 3 years of simulated treatments. However, these changes were not perceptible to the clinician.⁹⁰

Color stability of esthetic brackets made of different materials was evaluated using the Easyshade. The brackets were immersed for 10 days at 37 °C in various solutions, or exposed to accelerated photo-aging (150 kJ/m², 340 nm). It was found that the consumption of certain foods, such as red wine, tea, coffee and curry, greatly influenced the color changes of tooth-collared brackets.⁹¹

5.6. Tooth whitening

Color measurement devices have been used for bleaching studies to document shade changes.^{92–94} As indicated earlier,

one of the problems with shade matching especially for bleaching studies is positioning of the shade taking device. A flat surface is required to enable accurate placement during the shade measurement procedure. In addition, measurement near the incisal edge introduces error due to the translucent enamel allowing more light to be transmitted and not reflected to the shade taking device. Nonetheless, some clinicians feel a spectrophotometer can provide better comparison of shade change compared to a shade guide as a shade guide is non-linear. However a new Vita Bleachguide 3D-Master provides a more uniform color distribution in a linear fashion.⁹⁵ One study evaluated bleaching efficacy with and without supplementary light using Vitapan Classical and Bleachedguide 3D-Master in visual evaluation, and Easyshade spectrophotometer for instrumental evaluation.⁹⁶ A statistically significant difference between with- and without light treatment was registered using Bleachedguide and Easyshade, and greater color differences were recorded for baseline versus with light whitening. However, the ΔE^* values recorded in controlled conditions and by trained observers might not be perceivable in typical dental office conditions and by untrained observers. Clinical evaluation of different light-activated in-office bleaching systems revealed similar bleaching efficacy of four methods used: bleaching without light activation, diode laser activation, plasma arc lamp and a light emitting diode, with ΔE^* ranging from 5.3 to 5.7 (Easyshade).⁹⁷ Given the findings and less tooth and gingival sensitivity with diode laser, the authors suggested that this method might be the preferred in-office bleaching.

When two over the counter products, a 6% hydrogen peroxide (HP) bleaching gel delivered on polyethylene film and an 18% carbamide peroxide (CP) brush-applied liquid gel, were compared visually (Classical) and instrumentally (ShadeVision), both treatments caused significant tooth whitening. However, the HP-based product exhibited significantly greater efficacy.⁹⁸ Evaluation of the effect of laser tooth whitening revealed that teeth belonging to Classical group A showed greater shade improvement than teeth belonging to groups C and D. Whilst the whitening response was better in younger individuals, this response was not affected by gender. It should be noted that measurements were performed immediately after removal of the whitening gel, using ShadeEye NCC Dental Chroma Meter.⁹⁹ Another paper reported that Nd:YAG laser associated with hydrogen peroxide bleached the enamel, similarly to whitening efficacy obtained with the traditional method performed with halogen light.¹⁰⁰

Digital imaging has also been used for tooth whitening monitoring. In one study, digital imaging implied that 35% carbamide peroxide was more effective for darker teeth than 10% solution of the same agent.¹⁰¹ Several studies stated that their digital imaging system is reproducible and reliable in evaluating changes in whiteness of teeth¹⁰² and that clinical measurement of tooth color was highly reproducible with very high intra-class correlations for the image pairs.⁵³ Using the imaging system tested in reference 53, it was found that: (a) twice-daily use of 6% hydrogen peroxide whitening strips resulted in teeth becoming lighter and less yellow compared to baseline during initial 2-week use¹⁰³; (b) short-term color rebound after treatment may impact the utility of in-office tooth whitening with peroxide and light as a stand-alone

esthetic procedure¹⁰⁴; and (c) two professional at-home tooth whitening systems in a teenage population resulted in significant reduction in yellowness and increase in lightness after two weeks of treatment on each arch. No significant difference between groups was recorded.¹⁰⁵

5.7. Color interactions

Dental and professional color measurement devices have been used for quantifying of translucency-dependent color interactions. It was reported that different metal substructures and different porcelains significantly affected the final color of the restoration.¹⁰⁶ Changing the enamel porcelain thickness was found to have a greater effect on elevated chromatic shades compared to those of a lower chroma,¹⁰⁷ whereas semitranslucent all-ceramic materials achieved more accurate shade matches at reduced thickness of translucent porcelain than metal ceramic or semi-opaque all-ceramic crowns.¹⁰⁸ It was found that composite cements created perceptible color differences with particular combinations of die material, cement and ceramic crown,¹⁰⁹ and that final color of thinner specimens was significantly affected by the shade change and thickness of luting agent.¹¹⁰ Different backgrounds also influenced color of glass-infiltrated ceramic veneers,¹¹¹ whilst In-Ceram Alumina ceramic veneers showed the greatest improvement in the color performance of discolored teeth.¹¹²

In addition to layering, physical translucency can contribute to overall color shifting (color adjustment potential, blending) of restorative materials. Blending effect in the narrow sense is optical illusion, not measurable by any device, while more widely understood it also encompasses the objective and measurable shifting caused by physical translucency. Blending effect was found to be material and shade dependent, and it increased with the decrease of restoration size.¹¹³ It increased with the decrease of initial color differences and the increase of translucency.¹¹⁴ Blending effect and double-layer effect were found to be directly proportional and highly correlated.¹¹⁵

6. Conclusion

The blending of science and art is something the dental industry is primed for. Patients are demanding contemporary esthetic dentistry, which has prompted the industry to continuously raise the bar with regard to esthetic detail. Many factors can influence the perception of color; by taking advantage of today's shade-matching technology, the subjectivity of color assessment can be minimized and accurate diagnosis of a restoration's shade is more easily communicated.

Complete tooth surface and limited area tooth surface measurement devices exist and either measure the complete tooth surface providing a "color map" or a smaller diameter [3–5 mm] on the tooth surface, respectively. Complete tooth measurement devices average the color in a larger area versus limited area measurement devices which measure a smaller area. These instruments are all useful supplementary tools in color analysis for direct or indirect restorations, communication for indirect restorations, reproduction and verification

of shade. Color communication is best performed using reference photography with reference shade tabs from current shade guide systems obtained using digital camera.

Besides the clinical applications, dental color measuring instruments and systems are increasingly used in research. This includes evaluation of measurement uncertainties, comparison between visual and instrumental findings, visual color thresholds and research on color compatibility, color stability including tooth whitening and color interactions of human teeth and dental materials.

Chances are that new affordable high-quality color matching instruments and technology will contribute to successful work with color and esthetic dentistry in general, particularly if complemented with better color-related education and training of dental professionals and advancement of dental materials. Whenever possible, both instrumental and visual color matching method should be used, as they complement each other and can lead towards predictable esthetic outcome.

Conflict of Interest

Dr. Paravina is a paid consultant for Vita Zahnfabrik.

Acknowledgement

The authors would like to express their sincere appreciation to Dr. Ivan Ristic of the University of Nis School of Dentistry who helped in part with the literature reviewing.

REFERENCES

1. Clark EB. An analysis of tooth color. *Journal of the American Dental Association* 1931;18:2093–103.
2. Bergen SF. Color in esthetics. *New York State Dental Journal* 1985;51:470–1.
3. Preston JD. Color science and dental art. St. Louis, MO: Mosby; 1980.
4. Miller LL. Shade matching. *Journal of Esthetic Dentistry* 1993;5:143–53.
5. Yamamoto M. The value conversion a new concept for expressing the shades of natural teeth. *Quintessence of Dental Technology* 1992;19:9–13.
6. Evolution of materials. *Journal of Dental Technology* 2000;3:9–10.
7. Goldstein GR, Schmitt GW. Repeatability of a specially designed intraoral colorimeter. *Journal of Prosthetic Dentistry* 1993;69:616–9.
8. Yamamoto M. Development of the vintage halo computer color search system. *Quintessence of Dental Technology* 1998;21:9–26.
9. Miyoshi Y, Sasaki J. Clinical application of the computer color search system and digital recording method of the building recipe: use of the "Shade Eye file" database. *Quintessence of Dental Technology* 1999;1:69–77.
10. Chu SJ, Tarnow DP. Digital shade analysis and verification: a case report and discussion. *Practical Procedures and Esthetic Dentistry* 2001;13:129–36.
11. Miller L. Organizing color in dentistry. *Journal of the American Dental Association* 1987;115:26E–40E.

12. Đozić A, Kleverlaan CJ, El-Zohairy A, Feilzer AJ, Khashayar G. Performance of five commercially available tooth color measuring devices. *Journal of Prosthodontics* 2007;16:93–100.
13. Paravina RD, Majkic G, Imai FH, Powers JM. Optimization of tooth color and shade guide design. *Journal of Prosthodontics* 2007;16:269–76.
14. Paravina RD. Evaluation of a newly developed shade-matching apparatus. *International Journal of Prosthodontics* 2002;15:528–34.
15. Cal E, Sonugelen M, Guneri P, Kesercioglu A, Kose T. Application of a digital technique in evaluating the reliability of shade guides. *Journal of Oral Rehabilitation* 2004;31:483–91.
16. Tashkandi E. Consistency in color parameters of a commonly used shade guide. *Saudi Dental Journal* 2010;22:7–11.
17. Paravina RD. Performance assessment of dental shade guides. *Journal of Dentistry* 2009;37:e15–e20.
18. Paravina RD, Johnston WM, Powers JM. New shade guide for evaluation of tooth whitening-colorimetric study. *Journal of Esthetic and Restorative Dentistry* 2007;19:276–83.
19. Ahmad I. Three-dimensional shade analysis: Perspectives of color. Part II. Practical. *Periodontics and Esthetic Dentistry* 2000;12:557–64.
20. Li Q, Yu H, Wang YN. Spectrophotometric evaluation of the optical influence of core build-up composites on all ceramic materials. *Dental Materials* 2009;25:158–65.
21. Goodacre CJ, Paravina RD, Bergen SF, Preston JD. A contemporary guide to color and shade selection for prosthodontics. *American College of Prosthodontists* 2009. [educational DVD].
22. Paul SJ, Peter A, Rodoni L, Pietrobon N. Conventional visual vs spectrophotometric shade taking for porcelain-fused-to-metal crowns: a clinical comparison. *International Journal of Periodontics and Restorative Dentistry* 2004;24:222–31.
23. Khurana R, Tredwin CJ, Weisbloom M, Moles DR. A clonical evaluation of the individual repeatability of three commercially available color measuring devices. *British Dental Journal* 2007;203:675–80.
24. Kielbassa AM, Beheim-Schwarzbach NJ, Neumann K, Zantner C. In vitro comparison of visual and computer-aided pre-and post-tooth shade determination using various home bleaching procedures. *Journal of Prosthetic Dentistry* 2009;101:92–100.
25. 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;101:40–5.
26. Paul S, Peter A, Pietrobon N, Hämmerle CH. Visual and spectrophotometric shade analysis of human teeth. *Journal of Dental Research* 2002;81:578–82.
27. Da Silva JD, Park SE, Weber HP, Ishikawa-Nagai S. Clinical performance of a newly developed spectrophotometer system on tooth color reproduction. *Journal of Prosthetic Dentistry* 2008;99:361–8.
28. http://www.vita-zahnfabrik.com/resourcesvita/shop/en/en_3055212.pdf [accessed 06.04.10].
29. http://www.xrte.com/product_overview.aspx?ID=812 [accessed 06.06.10].
30. Ristic I, Paravina RD. Color measuring instruments. *Acta Stomatologica Naissi* 2009;25:925–32.
31. Kim-Pusateri S, Brewer J, Davis EL, Wee AG. Reliability and accuracy of four dental shade-matching devices. *Journal of Prosthetic Dentistry* 2009;101:93–9.
32. http://www.xrte.com/product_overview.aspx?ID=339 [accessed 06.04.10].
33. Blaes J. Today's technology improves the shade-matching problems of yesterday. *Journal of Indiana Dental Association* 2002–2003;81:17–9.
34. <http://www.clearmatch.com/index.htm> [accessed 06.04.10].
35. Raigrodski AJ, Chiche G, Aoshima H, Spiekerman C. Efficacy of a computerized shade selection system in matching the shade of anterior metal–ceramic crowns—A pilot study. *Quintessence International* 2006;37:793–802.
36. Bolt RA, ten Bosch JJ, Coops JC. Influence of window size in small-window measurements, particularly of teeth. *Physics in Medicine and Biology* 1994;39:1133–42.
37. Johnston WM. Color measurement in dentistry. *Journal of Dentistry* 2009;37:e2–6.
38. Zyman P, Etienne JM. Recording and communicating shade with digital photography: Concepts and consideration. *Practical Procedures and Esthetic Dentistry* 2002;14:49–57.
39. Fondriest J. Shade matching in restorative dentistry: the science and strategies. *International Journal of Periodontics and Restorative Dentistry* 2003;23:467–79.
40. Ishikawa-Nagai S, Yoshida A, Da Silva JD, Miller L. Spectrophotometric analysis of tooth color reproduction on anterior all-ceramic crowns. Part 1. Analysis and interpretation of tooth color. *Journal of Esthetic and Restorative Dentistry* 2010;22:42–52.
41. Yoshida A, Miller L, Da Silva JD, Ishikawa-Nagai S. Spectrophotometric analysis of tooth color reproduction on anterior all-ceramic crowns. Part 2. Color reproduction and its transfer from in vitro to in vivo. *Journal of Esthetic and Restorative Dentistry* 2010;22:53–63.
42. Paravina RD. Commentary. Spectrophotometric analysis of tooth color reproduction on anterior all-ceramic crowns. Part 1. Analysis and interpretation of tooth color. Part 2. Color reproduction and its transfer from in vitro to in vivo. *Journal of Esthetic and Restorative Dentistry* 2010;22:64–5.
43. Berns RS. Billmeyer and Saltzman's principles of color technology. John Wiley & Sons; 2000.
44. 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;98:353–8.
45. Karamouzos A, Papadopoulos MA, Kolokithas G, Athanasiou AE. Precision of in vivo spectrophotometric color evaluation of natural teeth. *Journal of Oral Rehabilitation* 2007;34:613–21.
46. Tung F, Goldstein G, Jang S, Hittelman E. The repeatability of an intraoral dental colorimeter. *Journal of Prosthetic Dentistry* 2002;88:585–90.
47. Ishikawa-Nagai S, Ishibashi K, Tsuruta O, Weber HP. Reproducibility of tooth color gradation using a computer color-matching technique applied to ceramic restorations. *Journal of Prosthetic Dentistry* 2005;93:129–37.
48. Wee AG, Lindsey DT, Kuo S, Johnston WM. Color accuracy of commercial digital cameras for use in dentistry. *Dental Materials* 2006;22:553–9.
49. Smith RN, Collins LZ, Naeeni M, Joiner A, Philpotts CJ, Hopkinson I, et al. The in vitro and in vivo validation of a mobile non-contact camera-based digital imaging system for tooth color measurement. *Journal of Dentistry* 2008;36:15–20.
50. Denissen H, Kuijken A, Đozić A. A photographic method to measure the color characteristics of healthy gingiva. *International Journal of Dental Hygiene* 2007;5:22–6.
51. Bayindir F, Bayindir YZ, Gozalo-Diaz DJ, Wee AG. Coverage error of gingival shade guide systems in measuring color of attached anterior gingiva. *Journal of Prosthetic Dentistry* 2009;101:46–53.
52. Carter K, Landini G, Walmsley AD. Automated quantification of dental plaque accumulation using digital imaging. *Journal of Dentistry* 2004;32:623–8.

53. Sagel PA, Gerlach RW. Application of digital imaging in tooth whitening randomized controlled trials. *American Journal of Dentistry* 2007;20:7A–14A.
54. Lath DL, Smith RN, Guan YH, Karmo M, Brook AH. Measurement of stain on extracted teeth using spectrophotometry and digital image analysis. *International Journal of Dental Hygiene* 2007;5:174–9.
55. Imai FH. Reviewing state-of-art imaging modalities and its potential for biomedical applications. *Journal of Dentistry* 2009;37:e7–14.
56. Okubo S, Kanawati A, Richards MW, Childress S. Evaluation of visual and instrument shade matching. *Journal of Prosthetic Dentistry* 1998;80:642–8.
57. 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. *Journal of Dentistry* 2009;37:e57–63.
58. Fani G, Vichi A, Davidson CL. Spectrophotometric and visual shade measurements of human teeth using three shade guides. *American Journal of Dentistry* 2007;20:142–6.
59. Gehrke P, Riekeberg U, Fackler O, Dhom G. Comparison of in vivo visual, spectrophotometric and colorimetric shade determination of teeth and implant-supported crowns. *International Journal of Computerized Dentistry* 2009;12:247–63.
60. Browning WD, Chan DC, Blalock JS, Brackett MG. A comparison of human raters and an intra-oral spectrophotometer. *Operative Dentistry* 2009;34:337–43.
61. Hugo B, Witzel T, Klaiber B. Comparison of in vivo visual and computer-aided tooth shade determination. *Clinical Oral Investigations* 2005;9:244–50.
62. Li Q, Yu H, Wang YN. In vivo spectroradiometric evaluation of color matching errors among five shade guides. *Journal of Oral Rehabilitation* 2009;36:65–70.
63. Hassel AJ, Cevirgen E, Balke Z, Rammelsberg P. Intraexaminer reliability of measurement of tooth color by spectrophotometry. *Quintessence International* 2009;40:421–6.
64. Della Bona A, Barrett AA, Rosa V, Pinzetta C. Visual and instrumental agreement in dental shade selection: three distinct observer populations and shade matching protocols. *Dental Materials* 2009;25:276–81.
65. Paravina RD. Critical appraisal. Color in dentistry: match me, match me not. *Journal of Esthetic and Restorative Dentistry* 2009;21:133–9.
66. Kuehni RG, Marcus RT. An experiment in visual scaling of small color differences. *Color Research and Application* 1979;4:83–91.
67. Ragain JC, Johnston WM. Color acceptance of direct dental restorative materials by human observers. *Color Research and Application* 2000;25:278–85.
68. Ruyter IE, Nilner K, Moller B. Color stability of dental composite resin materials for crown and bridge veneers. *Dental Materials* 1987;3:246–51.
69. Douglas RD, Steinhauer TJ, Wee AG. Intraoral determination of the tolerance of dentists for perceptibility and acceptability of shade mismatch. *Journal of Prosthetic Dentistry* 2007;97:200–8.
70. Lindsey DT, Wee AG. Perceptibility and acceptability of CIELAB color differences in computer-simulated teeth. *Journal of Dentistry* 2007;35:593–9.
71. Paravina RD, Majkic G, Del Mar Perez M, Kiat-Amnuay S. Color difference thresholds of maxillofacial skin replications. *Journal of Prosthodontics* 2009;18:618–25.
72. Paravina RD, Majkic G, Stalker JR, Kiat-Amnuay S, Chen JW. Development of a model shade guide for primary teeth. *European Archives of Paediatric Dentistry* 2008;9:74–8.
73. Analoui M, Papkosta E, Cochran M, Matis B. Designing visually optimal shade guides. *Journal of Prosthetic Dentistry* 2004;92:371–6.
74. Yuan JC, Brewer JD, Monaco EA, Davis EL. Defining a natural tooth color space based on a 3-dimensional shade system. *Journal of Prosthetic Dentistry* 2007;98:110–9.
75. Paravina RD, O'Keefe KL, Kuljic BL. Color of permanent teeth: a prospective clinical study. *Balkan Journal of Stomatology* 2006;10:93–7.
76. Cocking C, Cevirgen E, Helling S, Oswald M, Corcodel N, Rammelsberg P, et al. Color compatibility between teeth and dental shade guides in Quinquagenarians and Septuagenarians. *Journal of Oral Rehabilitation* 2009;36:848–55.
77. Đozić A, Kleverlaana C, Aartmanb I, Feilzer A. Relation in color of three regions of vital human incisors. *Dental Materials* 2004;20:832–8.
78. Đozić A, Kleverlaana C, Aartmanb I, Feilzer A. Relation in color among maxillary incisors and canines. *Dental Materials* 2005;21:187–91.
79. Fazi G, Vichi A, Corciolani G, Ferrari M. Spectrophotometric evaluation of color match to VITA classical shade guide of four different veneering porcelain systems for metal ceramic restorations. *American Journal of Dentistry* 2009;22:19–22.
80. Corciolani G, Vichi A, Goracci C, Ferrari M. Color correspondence of a ceramic system in two different shade guides. *Journal of Dentistry* 2009;37:98–101.
81. Wee AG, Kang EY, Johnston WM, Seghi RR. Evaluating porcelain color match of different porcelain shade-matching systems. *Journal of Esthetic Dentistry* 2000;12:271–80.
82. Browning WD, Contreras-Bulnes R, Brackett MG, Brackett WW. Color differences: polymerized composite and corresponding Vitapan Classical shade tab. *Journal of Dentistry* 2009;37:e34–9.
83. Da Costa J, Fox P, Ferracane J. Comparison of various resin composite shades and layering technique with a shade guide. *Journal of Esthetic and Restorative Dentistry* 2010;22:114–26.
84. Paravina RD, Kimura M, Powers JM. Color compatibility of resin composites of identical shade designation. *Quintessence International* 2006;37:713–9.
85. Fontes ST, Fernández MR, de Moura CM, Meireles SS. Color stability of a nanofill composite: effect of different immersion media. *Journal of Applied Oral Science* 2009;17:388–91.
86. Ergücü Z, Türkün LS, Aladag A. Color stability of nanocomposites polished with one-step systems. *Operative Dentistry* 2008;33:413–20.
87. Celik G, Uludag B, Usumez A, Sahin V, Ozturk O, Goktug G. The effect of repeated firings on the color of an all-ceramic system with two different veneering porcelain shades. *Journal of Prosthetic Dentistry* 2008;99:203–8.
88. Ozturk O, Uludag B, Usumez A, Sahin V, Celik G. The effect of ceramic thickness and number of firings on the color of two all-ceramic systems. *Journal of Prosthetic Dentistry* 2008;100:99–106.
89. Sailer I, Holderegger C, Jung RE, Suter A, Thiévent B, Pietrobon N, et al. Clinical study of the color stability of veneering ceramics for zirconia frameworks. *International Journal of Prosthodontics* 2007;20:263–9.
90. Pohjola RM, Hackman ST, Browning WD. Evaluation of a standard shade guide for color change after disinfection. *Quintessence International* 2007;38:671–6.
91. Wriedt S, Schepke U, Wehrbein H. The discoloring effects of food on the color stability of esthetic brackets—an in-vitro study. *Journal of Orofacial Orthopedics* 2007;68:308–20.
92. Joiner A. The bleaching of teeth: a review of the literature. *Journal of Dentistry* 2006;34:412–9.
93. Joiner A. Tooth color: a review of the literature. *Journal of Dentistry* 2004;32:3–12.
94. Joiner A. Review of the effects of peroxide on enamel and dentine properties. *Journal of Dentistry* 2007;35:889–96.

95. Paravina RD. New shade guide for tooth whitening monitoring: visual assessment. *Journal of Prosthetic Dentistry* 2008;**99**:178–84.
96. Ontiveros JC, Paravina RD. Color change of vital teeth exposed to bleaching performed with and without supplementary light. *Journal of Dentistry* 2009;**37**:840–7.
97. Gurgan S, Cakir FY, Yazici E. Different light-activated in-office bleaching systems: a clinical evaluation. *Lasers in Medical Science* 2009. [Epub ahead of print].
98. Cronin MJ, Charles CA, Zhao Q, Dembling WZ. Comparison of two over-the-counter tooth whitening products using a novel system. *Compendium of Continuing Education in Dentistry* 2005;**26**:140–8.
99. Lin CH, Chou TM, Chen JH, Chen JH, Chuang FH, Lee HE, et al. Evaluation of the effect of laser tooth whitening. *International Journal of Prosthodontics* 2008;**21**:415–8.
100. Marcondes M, Paranhos MP, Spohr AM, Mota EG, Da Silva IN, Souto AA, et al. The influence of the Nd:YAG laser bleaching on physical and mechanical properties of the dental enamel. *Journal of Biomedical Materials Research Part B Applied Biomaterials* 2009;**90**:388–95.
101. Lee KY, Setchell DJ, Stokes AN, Frankel NT, Moles DR. Subjective and photometric determination of bleaching outcomes. *Quintessence International* 2007;**38**:e41–7.
102. Luo W, Westland S, Brunton P, Ellwood R, Pretty IA, Mohan N. Comparison of the ability of different color indices to assess changes in tooth whiteness. *Journal of Dentistry* 2007;**35**:109–16.
103. Swift EJ, Heymann HO, Wilder AD, Barker ML, Gerlach RW. Effects of duration of whitening strip treatment on tooth color: a randomized, placebo-controlled clinical trial. *Journal of Dentistry* 2009;**37**:e51–6.
104. Kugel G, Ferreira S, Sharma S, Barker ML, Gerlach RW. Clinical trial assessing light enhancement of in-office tooth whitening. *Journal of Esthetic and Restorative Dentistry* 2009;**21**:336–47.
105. Donly KJ, Segura A, Henson T, Barker ML, Gerlach RW. Randomized controlled trial of professional at-home tooth whitening in teenagers. *General Dentistry* 2007;**55**:669–74.
106. Kourtis SG, Tripodakis AP, Doukoudakis AA. Spectrophotometric evaluation of the optical influence of different metal alloys and porcelains in the metal–ceramic complex. *Journal of Prosthetic Dentistry* 2004;**92**:477–85.
107. Jarad FD, Moss BW, Younston CC, Russell MD. The effect of enamel porcelain thickness on color and the ability of a shade guide to prescribe chroma. *Dental Materials* 2007;**23**:454–60.
108. Douglas RD, Przybylska M. Predicting porcelain thickness required for dental shade matches. *Journal of Prosthetic Dentistry* 1999;**82**:143–9.
109. Chang J, Da Silva JD, Sakai M, Kristiansen J, Ishikawa-Nagai S. The optical effect of composite luting cement on all ceramic crowns. *Journal of Dentistry* 2009;**37**:937–43.
110. Xing WZ, Wang YN, Chen X. Effect of the shade and thickness of luting agent on the color of solidex resin. *Hua Xi Kou Qiang Yi Xue Za Zhi* 2007;**25**:153–5.
111. Charisis D, Koutayas SO, Kamposiora P, Doukoudakis A. Spectrophotometric evaluation of the influence of different backgrounds on the color of glass-infiltrated ceramic veneers. *The European Journal of Esthetic Dentistry* 2006;**1**:142–56.
112. Koutayas SO, Charisis D. Influence of the core material and the glass infiltration mode on the color of glass-infiltrated ceramic veneers over discolored backgrounds. A spectrophotometric evaluation. *The European Journal of Esthetic Dentistry* 2008;**3**:160–73.
113. Paravina RD, Westland S, Imai FH, Kimura M, Powers JM. Evaluation of blending effect of composites related to restoration size. *Dental Materials* 2006;**22**:299–307.
114. Paravina RD, Westland S, Kimura M, Powers JM, Imai FH. Color interaction of dental materials: blending effect of layered composites. *Dental Materials* 2006;**22**:903–8.
115. Paravina RD, Westland S, Johnston WM, Powers JM. Color adjustment potential of resin composites. *Journal of Dental Research* 2008;**87**:499–503.