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Short Communication

Dental Shade Matching: Recent Technologies and Future Smart Applications

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Abstract

Shade matching in dental practice has been a great challenge for years. Shade matching has been carried out visually which proved unreliable and subjective. Alternatively, digital devices as spectrophotometer, colorimeter and digital photography were introduced which proved reliable but increased cost and time. The combination of patients requesting more esthetic restorations with dentists not willing to invest in expensive solutions, motivated researchers to investigate in new technologies for cost effective shade matching. Dental companies have offered smart apps with proposed techniques to benefit from high resolution built-in cameras of smart phones to facilitate shade matching. These smartphone-based colorimeter apps offered a low-cost, portable shade matching alternative, and allowed storing and sharing of the results. Accuracy and reliability of smart apps in dental shade matching are still questionable and requires development and optimization. It is recommended that researchers and software companies identify professionals' needs and to design appropriate technologies, that would improve and accelerate performance in color selection for both clinicians and dental technicians.

Keywords

Shade Matching; Dental Aesthetics; Smart Applications

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Introduction

Replication of complex tooth color in dental restorations has been a great challenge that confused practitioners over years. In the current days, even more challenging owed by the increased awareness of aesthetic standards by patients and the versatility of restorative materials [1]. Aesthetics is a crucial indication of good quality of life and dental professionals are required to address patients' expectations of achieving ultimate aesthetics.

Visual analysis using commercially available shade guides has been the most commonly used method to match shade in dental practice. Precision in shade selection was only attained when the restoration is the closest replication of neighboring natural tooth.

In the path of development of shade guides, different color systems were introduced to define color. The Munsell color system was proposed and it categorizes color into three dimensions; value, chroma, and hue (LCh-values). Value is determined by the lightness or darkness of the color, and ranges from white (10/) to black (0/). Chroma is determined as increasing saturation of the color which ranges from achromatic or grey (/0), to a highly saturated color (/18). Hue is the element of a color that distinguishes between different families and is measured on a scale from 2.5 to 10, in increments of 2.5 for each of the 10 color groups (R: Red; YR: Yellow-Red; Y: Yellow; GY: Green-Yellow; G: Green; BG: Blue-Green; B: Blue; PB: Purple-Blue; P: Purple; RP: Red-Purple) [2].

In 1976 the CIELAB color system was introduced by the Commission Internationale de l'Eclairage (CIE) [5]. In this system, color space is represented as three coordinates: L, a and b. "L" refers to the lightness coordinate, and its value ranges from 0 for black to 100 for white. "a" represents the coordinates in the red-green axis where positive values reflect the red color range and negative values indicate the green color range. "b" signifies the coordinates of the yellow-blue axis in which positive values indicate the yellow range while negative values indicate the blue range [2] .

Visual shade matching is highly subjective and considered unreliable owing to the multiple physiological and psychological variables. It has been affected by the examiner's experience, color perception, eye fatigue, and color of the background [3,4]. Visual shade perception requires standardization of the light source, the angle of illumination, and the distance between the light source and the tooth [5, 6]. Moreover, the high complex nature of the color distribution within a single natural tooth, together with tooth shape, surface quality, and brightness, may further complicate accurate observation of colors [7].

Shade Matching from Visual to Digital

With the purpose to overcome shortcomings of visual shade analysis, different electronic color measuring devices were developed to improve the accuracy and reliability of shade selection. Electronic devices as the spectrophotometer (which has been considered the gold standard in dental color screening research) [1]. In addition, colorimeters, spectroradiometers, digital camera systems with corresponding software and intraoral scanners [2,8-10]. Theses digital instruments arrived with acceptable accuracy of shade matching, and increased expenses and equipment adjustment [11].

Instrumental methods have evolved in practice to shift from subjective to objective analysis of color as expressed in numerical values throughout different systems of color parameters. The spectrophotometer is a device that comprises a stable light source directed to the examined surface and when reflected, it is detected by either a single photodiode detector that records the amount of light at each wavelength separately, or a more recent design of diode array that allows simultaneous integration of wavelengths [2]. Spectrophotometers were addressed as the most accurate and highly precise color matching instruments in dentistry [3,4]. Its color measurement is not affected by the surrounding light source, and color information could be provided in variable color parameters which simplifies color communication and comparison [6]. Kalantari, et al., compared the accuracy of shade selection using two spectrophotometer devices; Vita EasyShade and Shadepilot, and visual method. Both spectrophotometric systems were significantly better than the visual method [12].

Colorimeters on the other hand, used three or four silicon photodiodes that have spectral correction filters. These filters act as analog function generators that limit the spectral characteristics of the light striking the detector surface. These devices could be used for quality control because of their consistent and rapid sensing nature [2].

Kuzmanović and Lyons [8], reported insignificant differences in accuracy of shade selection between visual method using Vita Classical shade guide and Shade Vision colorimeter [8]. Gehrke, et al., evaluated the reliability and re-producibility of a spectro-photometer, a colorimeter and conventional human visual shade assessment on right maxillary central incisors free of any restoration and single implant-supported Porcelain Fused to Metal (PFM) crowns [1]. Reproducibility of the same shade was reported in an ascending order for human examiners, colorimetric readings, and spectrophotometric readings. The spectrophotometer exhibited the highest agreement between two consecutive readings and the results of the colorimeter showed distinctly lighter shades than those of the spectrophotometer. Degree of agreement differed significantly with the type of tooth being evaluated by the spectrophotometer devices, with the highest agreement in central incisor, while it did not differ in readings by the colorimeter [6].

The main advantages offered by the digital shade matching devices were manifested mainly in the no need to standardize the light environment in the dental clinic and the user independent accuracy and reliability [11,13]. Nevertheless these computerized systems added increased expenses, the contact type measuring instruments were only able to scan flat surfaces rather than curved teeth surfaces and teeth translucency could result in edge loss [11,14-16].

Recently, digital imaging and digital camera technology were developed and could offer an effective and less expensive alternative for dental shade matching. Digital photography offered significant benefits to dental practices due to their efficiency and ease of use. To get a full color image, digital sensors uses filtering to capture light in its three prime colors (red, green, and blue) in a manner close to the filtered colorimeter. The highest-quality cameras uses three separate sensors, each with a different filter over it so that the camera record each of the three colors at each pixel location [2].

Culic, et al., evaluated a computer software (Toodent) where digital photographs of VitaPan 3D Master shade tabs were captured using photographic system (body Canon 400D, Canon 100mm lenses, and CanonMR14-EX ring flash) and analysed [17]. In order to evaluate the accuracy of the program, readings were compared to measurements of a spectrophotometer in L, a, b values. Results indicated good accuracy of the experimental system though further evaluation was recommended with wider color scale to evaluate its efficiency in routine clinical color selection.

Miyajiwala, et al., compared three different methods for shade selection of sound right maxillary central incisor [9]. Methods used were visual analysis, clinical spectrophotometer and digital photography with a Canon 500 D series digital camera. The digital images were further processed using Adobe Photoshop software. Digital photography appeared as a consistent method for shade selection in a clinical setup. Furthermore, Siddique, et al., reported that shade matching in digital photographs recorded at distance of 30 cm showed statistically higher correct identification than those captured at 10 or15 cm [18].

Intraoral scanners that were initially designed to produce instantaneous digital dental impressions, were upgraded to aid in simultaneously selecting dental color such as the 3Shape TRIOS system. This digital scanning and computer software system for color determination, demonstrated reliability higher than that for the conventional visual system and comparable to digital spectrophotometer system [19].

The repeatability of the intraoral scanner (3Shape TRIOS) was compared with the traditional visual method for dental shade matching in vivo. The scanner recorded higher accuracy than the visual analysis by dentist and dental technician. But still below the accuracy of the reference spectrophotometer system [10]. The same system was examined on patients under different

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lighting conditions, and results showed that the intraoral scanner obtained a significant higher mean repeatability of dental shade matching compared to the visual method [20]. Kim, et al., developed a digital shade-matching device utilising a modified intraoral camera to measure 3D shade tabs, which reported more than 90% matching accuracy and less than 1% failure rate [21].

Smart Applications in Modern Dentistry

Smart mobile devices as smartphones; tablets; ipads; and others, are computerized personal digital aides with incorporated high-speed Internet connectivity. The use of smart apps is a rapidly growing practice in dental healthcare delivery, and could provide an effective means to complete a remarkable group of multifaceted missions simply and efficiently [22].

Smart phones are extensively used worldwide and have become an integral part of routine daily practice. Interconnectivity has increased 1,187 % from 2000 to 2020, based on data from the United Nations Population Division. 59.6% of the world population are using internet, and 70.2% of the Middle East population were recorded using internet applications [23]. The availability and ease of using smart applications (apps) by mostly all categories of the population encourages the idea of their benefit in dental health care and education [24].

The evidence base of mobile apps is to facilitate daily practices of the dental professional, concurrently with enhancing and accelerating tasks, optimizing work time, and facilitating communication with the dental technicians. As the mainstream of dental practitioners and patients, own smart mobile devices with high-speed Internet connectivity, then the facility to run customized software applications, to aid dental practitioners could be serviceable [23].

Smart apps are appropriate in capturing patient demographic data, scheduling appointments, interaction with insurance companies, initiating and tracking billings, and generating reports [25,26]. They as well, facilitated information exchange in which dentists can receive clinical information captured by the patients and delivered as text, voice recording, or high-resolution photographs [27]. Using interactive apps, practitioners are able to demonstrate visually and interactively the detailed state of the patient’s dental health, and proposed treatment [24,28]. Smart apps enhanced patients motivation and education, and provided a feasible means for consultations and health advice [29]. A cross-sectional study was conducted to evaluate the features of current oral health education smart apps, and a total of 146 oral health apps were reported, the most common were related to techniques of oral hygiene, and tooth brushing timers [28].

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Smart Apps and Dental Shade Matching

The use of smartphones with high-resolution photographic technology and interactive apps, provides a promising substitute in dental shade matching. Smartphones offer an accessible, portable, cost effective, more rapid and easier mode of recording. In addition it facilitates communication between the dentists and the dental laboratory. Yet, in certain complex clinical situations, the quality of image required might be one criterion that favors a higher resolution professional digital camera over the camera builtin within the smart phone [30].

Recently, mobile apps that can analyze color of an image portion and determine its components according to the chosen color space, has been available and can be used to match the color of the tooth to a selected shade guide system [31,32].

Tam, el al., proposed a dental shade matching system using digital images caught by a smart phone camera at different clinical situations of shooting distances and illumination [33]. Shade tab images were recorded using the smartphone camera with auto-mode settings and no flash. The proposed method supported using consumer smartphone cameras and provided evidence that fixing the position of shade guides, rather than randomly positioning them lead to superior shade classification results.

Application developer Stefano Bravi proposed an assistant app for smartphones called “TShade” that was designed for matching shades of teeth with sample tabs. It was based on taking a photo by the smart phone camera of the proposed tooth under uniform light conditions. The app had the ability to read tooth color in L, a, b values and to compare the color of the selected tooth area with sample images of the shade tabs, then produce a dialogue box with the closest best match to the tooth color and the second-best match. Results appeared as difference in color between the sample and the specific patient's tooth. If these values were less than or equal to 1.25, the difference will be unacceptable match; between 1.25 and 2.25, the difference was acceptable as the first best match; greater than 2.25 will be indicated as the second best sample [34, 31].

The DMP Dental Chromatcher, is a shade guide applications, proposed to enable dentists or technicians to deliver restorations of appropriate shade effortlessly. To determine a patient’s tooth shade, users take a photo of the desired tooth area and matched it with DMP’s shade system for restorative materials. Immediately, it was possible to distinguish the needed shade, escaping the use of conventional shade guides. This application was available for use with the iPhone, iPad, and iPod touch, and was downloaded from the App Store for free [35].

In a comparison of accuracy and reliability between visual shade matching, a spectrophotometer, and two dental shade matching smartphone applications (SMART, Dental

Tooth Shade Recognition (DTSR) and Chromatcher (CHROM), in an invitro setting. The spectrophotometer showed the best results followed by the visual shade matching. Weak results in terms of accuracy and repeatability were reported for both smartphone applications which tended to measure the same dental shade, in which DTSR showed tendency for dental shade A2, while CHROM showed a tendency to selecting A3.5 and B2 for most of the color measurements [5].

In an alternative technique, shade matching was described through converting a captured photo of the designated tooth into a gray scale through the monochrome function of the smart phone. Then selection of the appropriate shade was based on the closest value of the shade tabs processed in the same way [36]. Later a detailed clinical protocol for shade matching using the monochrome concept was defined by Albert, et al., in which a photograph of 3D VITA shade guide was taken through a smartphone camera using natural light [37]. Then a patient tooth was photographed, and the two images were processed to black and white scale (monochromatic) to choose the value of the shade. After adequate selection of the value, the choices for hue and chroma were then made. The selected shade was investigated by a spectrophotometer which provided the same shade as that selected by the smartphone protocol. Nowadays a number of non-dental specified color analyzing apps are available from the app store and can analyze the color of an existing image into different forms of color spaces as RGB, L, a, b and others. Some of these apps could be beneficial in the dental practice if it allows comparison of the shades of two selected images as that of the patient tooth and an image of the shade guide. Nafea, et al., investigated two non-dental specific mobile Apps that can analyze color of an image in terms of RGB values [38]. Color readings of the two Apps were recorded and reliability was tested by repeating the readings after 7 days under similar conditions. Results showed significant difference between the two apps in all color ranges, especially the B value and it was suggested that the degree of accuracy was relatively low, as well as reliability after multiple readings.

Color reading dental-specified apps were developed by the dental companies and are compatible with both android or iOS systems and some of which are free to download. Smile Shade is an iOS software application that was developed to facilitate a simple, accurate, and systematic approach for dental shade determination, although it should be paired wirelessly with a color scanning device. The device requires approximately 2 seconds to generate a color mapping of the material, then the application creates a multiple screen display of the color. The file is stored on iCloud and may be downloaded or emailed for communication. It offers the evaluation of color based on CMYK (Cyan, Magenta, Yellow and Key (Black), RGB (Red, Green and Blue), and Lab systems [39].

One of the innovations from Ivoclar Vivadent is the “IPS e.max Shade Navigation App (SNA) which is compatible with Android and iOS devices and has been available free of charge. The

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app finds the correct shade and level of translucency for all IPS e.max restorations, enabling relaxed shade matching procedures. Zirconia materials (discs and blocks) were added to the SNA in 2017 to go along with the lithium disilicate materials. SNA app received the Fachdental Award 2017 - a prize that honours innovative dental ideas, products or prototypes, at two trade exhibitions in Germany [40].

ShadeWave is another alternative shade matching application for iphone. ShadeWave is a patented software that creates shade maps of any desired shade guide, custom shade guides, and even gingiva colors. It uses shade tabs as a reference for color correction to reveal the unknown tooth shade. As tooth color is complex and one shade tab in a picture is never adequate, Shade wave has the ability to reveal all possible colors. This application has the ability to fix captured pictures, thus allows reading shade from too dark, too light or low-resolution photographs. In this way, it reduces lab labor time and minimises errors when compared manual processing. It offers as well, shade communication and photo documentation and exchanging between the dentist and the dental technician through cloud based, secure server [41].

Conclusion

Digital dental shade matching devices were developed to eleminate the subjectivety of the most commonly used visual method. Out of these devices the spectrophotometer is considered the gold standrad in the realiability and reproducibility of shade matching. Digital photographs and intraoral scanners with the associated software represents a consistent alternative in shade matching with results comparable to the spectrophotometer. Specialized and non-specialized shade matching smart apps are available and were investigated in regard to cost efficiency, familiarity, ease of use, and accuracy in shade matching. Smart apps allow storing and sharing of the results on the phone memory or iClouds along with the user identity. However, accuracy and reliability of dental shade matching apps are still questionable and requires continuous development and optimization with the beneficence of the high-quality smartphones built-in cameras. Researchers and software companies need to identify professionals’ needs regarding shade matching and to design and implement new and appropriate smart apps.

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