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Digital Shade Matching: An Insight.

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ABSTRACT

Every patient wishes for prosthesis which looks more like a natural tooth. One the most prime criteria to achieve this goal is by matching appropriate shade with the adjacent teeth. Shade selection has evolved from visual technique to instrumental technique, thus shifting subjective measurement to more objective measurement. This article gives an insight into the various digital shade matching systems highlighting the differences between visual shade selection and advanced techniques.
Keywords: natural tooth, shade, visual technique.

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INTRODUCTION

Esthetic demands in today's world of dentistry are scaling new heights, and are driven by the zest to look beautiful. Shade matching is the preliminary step in fabrication of restoration or prosthesis. To have a life like effect, shade of the target tooth should be accurately matched and then accordingly communicated to laboratory technician. There two ways of measuring color, one is through the use of shade guides and other through the use of shade matching instruments which comprises of spectrophotometer, colorimeter, and digital camera along with imaging systems [1].

Selecting shade through shade guide is subjective and depends on various factors like surrounding illumination, clinicians color perception and experience, background of tooth, and the shade guide used [2,3]. Since technician does not usually see the patient’s tooth shade and has to work on the basis of dentist’s written prescription, a laboratory communication made by dentist is of utmost importance. Shade guide tabs are thicker than the thickness of porcelain used for restoration and also fluorescence of shade guide is different from that of natural teeth, thus making shade selection more challenging for dentist to obtain a correct shade on the prosthesis [4-9].

Limitations in shade selection through shade guide, led to development of shade matching instruments which perform objective measurements and rely on computer calculations. These are more repeatable, accurate and rapid than visual shade matching [10-12].

Shade selection can also be done through photographic images which are taken through digital camera. Images are transferred to computer and analysed using imaging software [13-15]. It is less expensive as compared to spectrophotometers and may provide the entire spectrum of color space for natural teeth. It is objective method of shade selection and efficient tool for communication with a dental laboratory [16,17]. (Table 1).

Table 1: Measurement of color can be divided into subjective technique and instrumental technique.

Subjective technique (Visual technique)	Objective technique (Instrumental technique)
A. Shade guide	A. Spectrophotometer B. Colorimeter C. Digital cameras and imaging systems

Methods of shade selection in dentistry

Subjective technique (Visual technique)

Visual determination of color is based on Munsell color system, parameters of which are represented in three dimensions. Color is determined in terms of hue, value and chroma [18]. Hue is specified as dominant range of wavelengths in the visible spectrum that yields the perceived color. Hue describes the dominant color of an object, for example, red, green, or blue. Value is the amount light returned from an object. It is described as lightness or darkness of a color. Chroma is the saturation, intensity or strength of the Hue [19]. Selection of tooth shade first starts with choosing the nearest hue, and then appropriate match of chroma and value from the tabs, which might be A, B, C or D.(Fig 1) Once the hue is selected, the best chroma match is chosen. For example, if a B hue is determined to be the best match for color variety, there are four available gradations (tabs) of that hue: BI, B2, B3, and B4. Between comparisons, glancing at a blue object will rest the operator's eye and help avoid retinal cone fatigue. Finally, value is determined with a second commercial guide whose samples are arranged in order of increasing lightness [20]. An individual will be able to assess the value most effectively by observing from a distance, standing slightly away from the chair, and squinting the eyes. By squinting, the observer can reduce the amount of light that reaches the retina. Stimulation of the cones is reduced, and a greater sensitivity to achromatic conditions may result. While squinting, the observer concentrates on which disappears from sight first-the tooth or the shade tab. The one that fades first has the lower value [20]. There are various commercially available shade guides which are Vita Lumin shade guide, Vitapan 3D-Master shade guide and Chomascop shade guide. (Fig 2)

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Figure 1: Shade selection using shade guide.

Figure 2: Vita classical shade guide.

Objective technique (Instrumental technique)

Table 2: Digital shade matching systems

System	Manufacturer	Type of unit	Type of measurement
ShadeEye	Shofu Dental Corp., San Marcos, CA	Colorimeter	Spot on tooth
Vita EasyShade	Vident, Brea, CA	Spectrophotometer	Spot on tooth
ShadeScan	Cynovad Inc., Montreal, Quebec, Canada	Digital color imaging/colorimeter	Complete tooth
Shade-X	X-Rite, Grandville, MI	Spectrophotometer	Spot on tooth
SpectroShade MHT,	Niederhasli, Switzerland	Digital color imaging/ spectrophotometer	Complete tooth
ClearMatch	Smart Technology, Hood River, OR	Software only (to be used with digital camera)	Complete tooth
Crystal eye	Olympus, Tokyo,Japan	spectrophotometer	Complete tooth

In instrumental technique of shade selection, color is quantified by using a color order system developed in 1976 by the Commission Internationale de l'Eclairage (CIE), which uses 3 values, L*, a*, and b* [21]. The CIE L* value is a measure of the lightness of an object, the CIE a* value is a measure of redness (positive value) or greenness (negative value), and the CIE b* value is a measure of yellowness (positive value) or blueness (negative value) [22]. The L* value in the CIELAB system measures lightness and correlates to value (V) in the Munsell color order system. The a* and b* values can be used to derive the metric chroma ($C^*_{ab} = (a^2 + b^2)0.5$) and hue angle ($h_{ab} = \tan^{-1}(b/a)$) as defined by CIE (1986) [23,24]. A color difference (ΔE) between two objects can be calculated according to the following equation: $\Delta E= ((L_1^*-L_2^*)^2+(a_1^*-a_2^*)^2+(b_1^*-b_2^*)^2)0.5$ within the CIE LAB color system [24,25]. Various techniques have been reported in literature which use advanced digital technology for shade selection. All color-measuring devices consist of a detector, signal conditioner, and software that process the signal in a manner that makes the data usable in the dental operatory or laboratory [26]. (Table 2) [27].

Type of measurements used in digital shade selection

Digital shade selection is based on two types of measurements namely spot measurement and complete tooth measurements.

Spot measurement

Devices based on this principle measure a small area of tooth surface. Since diameter of the optical device is less, it cannot deliver all the information necessary to create a whole image of tooth. Spot measurement device generally require three points of reference on a tooth surface [25]. This increase in number of references lead to more errors while image is captured and also increases the time for shade information data capture. Therefore spot measurement is more useful in showing shade trends or tendencies and should be used as an adjunct to visual shade matching process [25]. Example of spot measurement devices are Vident EasyShade Compact system and X-rite Shade-X.

Complete tooth measurement

These digital systems measure entire tooth surface, thus providing a complete shade mapping of tooth. It provides all the information in one image thus gives the operator more consistent and reproducible information of the tooth surface. Because of the size of the sensor, their use is limited to anterior teeth. Example of these devices are the MHT SpectroShade and the Olympus CrystalEye [10,28].

Digital shade matching systems

Spectrophotometer

One of the most accurate, highly precise and flexible instrument for color matching in dentistry is the spectrophotometer [25,26]. It is relatively simple and easy to use. Spectrophotometers measure the spectral reflectance or transmittance curve of an object. They have a longer working life than colorimeters and are useful in the measurement of surface color. It records and measures the amount of visible light for each hue, value and chroma present in the entire visible spectrum [29]. It consist of a single photodiode detector, a source of optical radiation and monochromator to convert light into signal that can be analysed [26]. (Fig 2). Measurement obtained by the instrument are converted to shade guide equivalent for shade matching. Major drawback of this instrument is its complex design and its high cost [25].

Various types of spectrophotometers are

- Vita Easyshade compact (Vita Zahnfabrik, Bad säckingen, Germany)
- Shade-X (X-Rite, Grandville, MI)
- SpectroShade Micro (MHT Optic Research, Niederhasli, Switzerland)
- Crystal eye (Olympus, Tokyo,Japan)

Vita Easyshade compact (Vita Zahnfabrik, Bad säckingen, Germany)

The Vita Easyshade (Vident, Brea, California) is a cordless, portable, and lightweight hand-held spectrophotometer that consists of a hand piece connected to a base unit by a monocoil fiberoptic cable assembly [28,30]. The contact probe tip is approximately 5 mm in diameter [26]. Light from the halogen bulb in the base unit is directed into the tooth surface and tooth is illuminated by the periphery of the tip. A combination of various filters and photodiode arrays receive the light as it is directed through the return fibers located in the centre of the probe tip. Through this arrangement, spectral reflectance of the scattered light is essentially measured in 25 nm bandwidths [26]. The dentist or assistant have to select the tooth to be measured and then to place the tip of the spectrophotometer hand piece directly on the tooth. A button is pressed, and the display presents the closest Vita shade in the classical or 3D shade guide designation [30]. Advantage of Vita Easyshade compact is its portability, patient comfort and accessible in posterior region. Disadvantage of Vita Easyshade compact is that it gives poor result due to incorrect positioning of the device [25].

Shade-X (X-Rite, Grandville, MI)

It is compact and cordless spot measurement spectrophotometer with 3-mm probe diameter that analyses the shade of the tooth to be restored and the surrounding teeth with specialized image software. Shade-X has two databases to match the color of the dentin (more opaque) and the incisal tooth regions (more translucent) [27]. It has cone shaped sensor which is pointed at the tooth and the image is acquired. As the unit is returned to its docking station, software is initialized. Shade data is analysed and software selects most appropriate shades from the designated ceramic system. Software conducts a step wise process which involves measurement of color, mapping of tooth, applying the shade guides, and prescribing the shade for laboratory use. Files stored in the unit can be easily transmitted via internet [30].

SpectroShade Micro (MHT Optic Research, Niederhasli, Switzerland)

It combines digital color imaging with spectrophotometric analysis [26]. It uses a dual digital cameras linked through optic fibers to a fully functional spectrophotometer [30]. The system measures the color characteristics of the natural tooth and indicated the deviations in value, chroma and hue from standard parameters, thus providing all the information required for modifying the restoration and accurately matching the tooth. The handpiece is relatively large compared with the contact probe designs. Calibration is a two-step process involving positioning the handpiece against white and green tiles. Light from a halogen source is delivered through fiber optic bundles and lenses to the tooth surface at 45 [26]. The image of the tooth is displayed on the computer screen so that positioning can be verified. Color differences can be calculated between compared images, and shade maps of increasing complexity.[26] Software contains reference shade according the ceramic systems. Closest shade to the selected tooth and magnitude of color difference can be specified, thus results are highly accurate. All the data can be transmitted electronically or by print out to the laboratory [26]. Major drawback of this instrument is its cost and minimal access to the molar region [25].

Crystal eye (Olympus, Tokyo,Japan)

It combines a traditional spectrophotometer with digital photography. The Crystaleye Spectrophotometer uses light-emitting devices (LEDs) as an illumination source. The color-measuring section consists of a spectrophotometer with a liquid crystal display (LCD) monitor, a cradle for calibration and data transmission to the computer, and a contact cap [32]. Crystaleye Spectrophotometer is calibrated using a reference plate installed at the edge of the cradle. As a result, the necessary standard color information for measuring could be obtained. After calibration, a contact cap is attached, and the color measurement is started. The captured images transmitted via a USB cable to a personal computer and processed with the Crystaleye Application Master software for image analysis. Crystaleye Application Master automatically identifies the color measuring area of the cervical, body, and incisal areas of the target tooth, and color analysis data of the three areas are displayed [31]. One of the advantages 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 [27].

Colorimeter

These instruments approximate the spectral function of the standard observer's eye and are engineered to directly measure color as perceived by the human eye. Colorimeter measure tristimulus values and filter light in red, green and blue areas of the visible spectrum [25]. They generally use 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 [26]. The colorimeters are considered inferior to scanning devices such as spectrophotometers and spectroradiometers because of the inability to match the standard observer functions with filters while retaining adequate sensitivity for low light levels [26]. However, because of their consistent and rapid sensing nature, these devices can be used for quality control [26]. ShadeEye is an example of a colorimeter based on the natural color concept.

Shofu ShadeEye NCC (Shofu Dental GmbH, Ratingen, Germany)

It a mobile, wireless measuring unit that analyses the tooth shade digitally and instantaneously transmits the information to the main unit through an infrared interface. Its software calculates the appropriate porcelain mixture that will provide the exact color that has been scanned by the mobile unit. Apart from calculating the ceramic mixture requirement for Shofu's Vintage Halo porcelain, it also provide information for other shade guide and ceramic [20].

Cynovad Shade Scan (Cynovad, Montreal, Canada)

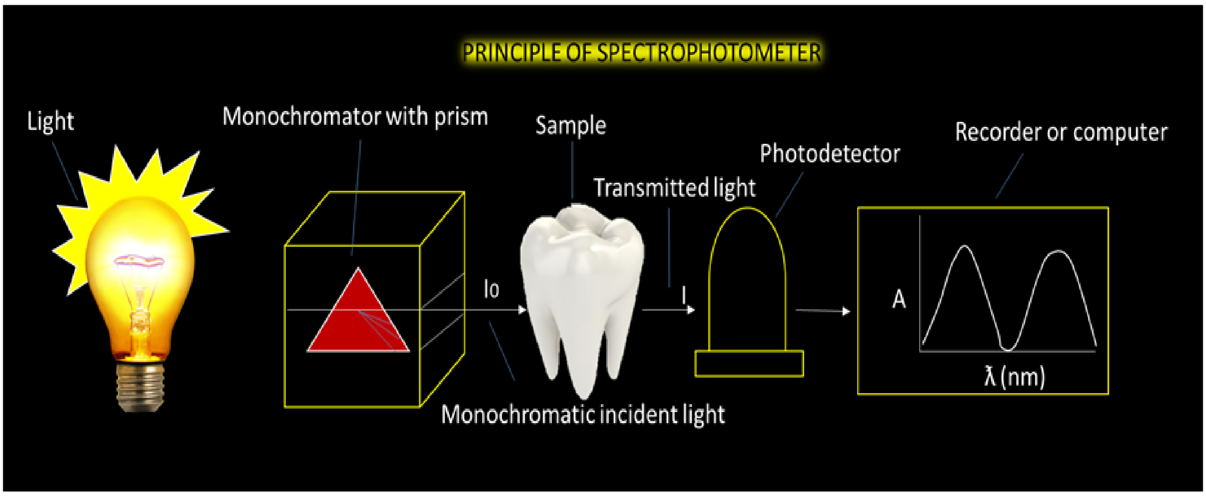
It is the first system to combine digital color imaging with colorimetric analysis.[26] It is provide consistent, accurate and instant measurements [30]. It has color LCD screen to aid in image location and focus. Tooth is illuminated through halogen light source at 45^0 angle and collects the reflected light at 0^0. Image is saved in a flashcard which can be downloaded to a computer having ShadeScan software. Software generates a color mapping of the tooth according to selected shade guide [26]. ShadeScan creates full tooth translucency maps to facilitate fabrication of esthetic restoration. Shade and translucency can be transmitted to laboratory by email, print out or flashcard [26].

Digital camera and imaging system: (Fig 3)

Most 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 [25]. Digital cameras and other RGB devices represent the most basic approach to electronic shade taking, still requiring a certain degree of subjective shade selection with the human eye [32]. Various approaches to the translation of this data into useful dental color information have been used. The information accuracy of RGB devices is questionable because they do not measure color, instead they infer color properties of the captured image. These systems provide lab technicians with a reference point, rather than visually determining shade of the teeth [25].

Digital camera is extremely efficient and easy to use. Digital photography can be an ideal adjunctive tool for the dentist and lab technician to quantify shade. However, the use of a digital camera alone is not effective for shade analysis [25]. A shade-matching protocol comprises of digital cameras, a grey card, and Adobe Photoshop, which is not yet feasible in everyday practice [25].

Figure 3: Principle of Spectrophotometer.



ClearMatch System (Smart Teachnology, Hood River, Oregon)

It is a software system that requires a computer having Windows operating system and a digital camera [26]. The software uses high resolution digital images and compares shades over entire tooth with known reference shades [27]. To calibrate the digital color signal, a black and white standard and a shade tab must be included in each photograph. Since it is a software, it is economical to use [26].

Factors affecting shade matching in different technologies

Tooth surface- smoother tooth surface will appear brighter, thus giving false reading. To solve this problem, some shade matching systems use filters to adjust for the surface lustre [25].

Edge loss- it is the loss of light caused through translucent tooth and ceramic enamel layers. Although algorithms are incorporated into the software to accommodate for different light scattering properties of teeth, crown, and shade tabs, it is difficult to fully compensate for these differences, and this can be a significant source of error [25,26,33].

Translucency- translucency of tooth structure is very difficult to replicate with the help of all the present systems. Systems having digital imaging has the best chance of mapping translucency because of high quality visual [25].

Positioning of probe- positioning of probe is very important for the repeatability of the measurement. Any device having small diameter contact probe cannot give detailed mapping of color on the surface whereas larger diameter probe can only be used in anterior region [26].

Comparison between visual and instrumental technique

Initially the accuracy of shade matching instruments were slightly better than visual technique. More recently, better results were reported with dental spectrophotometer than using the visual method in approximately 47% of the cases.[34] Another study stated that the performance of Easyshade is better than that of dentists [35]. 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 [27].

CONCLUSION

Shade matching instruments measure either complete tooth surface or a spot on tooth. Complete tooth measurement gives the entire color mapping of the tooth as compared spot measurement.

Precise color communication with laboratory is very vital for the fabrication of prosthesis. Most of the shade matching instruments store shade information which can be transmitted to laboratory by email, printout or flash card. Digital photography with reference shade tab is one the best method for communication of shade.

One of the major drawbacks of these instruments is their high cost as compared to visual shade guides. Digital photography and image analysing software are comparatively affordable with adequate precision. Visual technique which involves shade guide is not inferior to instrumental technique since latter needs more research for its further development and proves its efficiency thus, we should use instrument technique as adjunct to visual technique.

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