Review Article

Shade matching in fixed prosthodontics using instrumental color measurements and computers

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Instrumental color measurement could be preferred over visual color determination in fixed prosthodontics because instrumental readings are objective and more rapid. A measuring device permits precise shade selection without subjective impressions from the surroundings. Newer methods of shade selection include computerized shade matching systems that have appeared in the market.

Key words: Computers, instrumental color measurement, shade matching

INTRODUCTION

The goals of instrumental color measurement in dentistry are the valid intraoral optical electronic determination of a target color and verification of porcelain color during the fabrication of the restoration.[1] Colorimeters have been produced but the most reliable ones are contact types, which cannot be disinfected or sterilized. In an effort to overcome this problem, a non-contact colorimeter was modified with a powerful light source for possible use in the oral environment.[2]

Computerized shade matching systems offer better accuracy, improved efficiency and esthetic benefits to the patient, dentist and technician. These systems analyze the color of the natural tooth and calculate the exact rates of the hue, chroma and value for a multitude of points on the tooth surface and display this information on the dentist's computer screen. The process eliminates the guesswork often associated with reading the shade tabs and greatly facilitates the communication of information to the laboratory technician. The value of this technology to the individual practice must be determined not just as a single cash outlay but as a purchase that improves the quality and predictability of treatment and saves time.[3] Further, the improved flow of information encourages the fabrication of predictably accurate, highly esthetic restorations with greater confidence.

RATIONALE

Visual shade matching is subjective, consistency is difficult to achieve. *Photometric and colorimetric analysis* techniques offer great potential as tools for the objective evaluation of color and for aiding in duplication process.

The rationale is to aid in:

1. Material selection and restoration design.
2. Quantify color and enable communication to be rapid and more uniform and precise.
3. Determination of visual threshold for acceptability of shade mismatch, especially for restoring anterior teeth.
4. To enhance patient cooperation, motivation and compliance by satisfying the esthetic needs of the patient.

Computerized shade matching system includes hardware and software that identifies the variously colored, translucent, reflection and characterized areas of a tooth. The information provides a computerized shade map and offers considerably more information. It eliminates subjectively frequent perception errors. There is no requirement for standardizing the light environment of a dental operatory. Thus, shades can be taken anywhere, anytime.

DISCUSSION

The combination of light, colorant, eyes and brain describes the complex nature of the color.

The international standard for color measurement is represented by the (CIE) - International Commission on Illumination color order system and incorporates a standard observer, a co-ordinate system and the following standardized light sources (denoted by A, B and C):[4]

A = Gas-filled incandescent lamp, 2854°K
B = Noon sunlight, 2870°K
C = Average overcast sky daylight, 6500°K. A standard observer is a "mathematical description of the average human response to color stimulation."

The basic CIE concept [Figure 1] is that all colors can be matched by mixing relative amounts of the three light primaries: Red (X), Green (Y) and Blue (Z). The specified amounts of each light primarily required to match the color of a sample is numerically described by *x*, *y*, *z* that are called tristimulus values. The tristimulus values are recognized units of color measurement used in conjunction with the CIE color order system.[5] The comparison of color evaluation between the colorimetric devices and human observer responses showed that the differences in color interpretation can be easily reconciled with the use of CIELAB colorimetric system. A high degree of correlation can still exist between color-difference measurements, regardless of the design of the instrument. The highly trained human eye can detect color changes when ΔE is greater than 0.4.[2] It is derived from the following formula:

$$\Delta E = (\Delta L^*)^2 \ \Delta \ (\Delta a^*)^2 \ \Delta \ (\Delta b^*)^2$$

COLORIMETERS PROVIDE MEASUREMENTS IN CIELAB UNITS (*L**, *A**, *B**) THAT CAN COMPARE THE COLOR PARAMETERS OF DIFFERENT OBJECTS WHEN ANALYZED MATHEMATICALLY

Based on technology, colorimeters can be of two types.[6]

- Photoelectric tristimulus colorimeters (Microcolor)
- Silicon photodiode array (Orient Scientific Ltd.)

Photoelectric trisimulus colorimeters have the potential to remove some of the variables found when the visual method is exclusively used. These variables can be partially controlled by the use of a positioning template that allows the machine to read the same general area of tooth. The Colorton colorimeter is dependent on color difference formula $\Delta E = [(L_2 - L_1)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2]$ to accurately calculate the color difference from the obtained data. The accuracy and usefulness of the Colorton match tool is dependant on the ability of the color difference formula to generate values that correlate with the average visual responses of an observer.[7]

Figure 1: CIE (*x*, *y*) chromacity chart showing how the colors are distributed

Microcolor colorimeter (a Photoelectric tristimulus colorimeter) is a self contained measuring system that requires no external power source. In this type of apparatus, dyed polymer optical filters - each corresponding to one of the primary colors - are deposited on the top of the photodetector cells in a specific pattern. Each photodetector will then produce an output signal that is determined by the transmittance characteristics of the overlying optical filter. This construction allows the intensity of each primary color component of the incident light to be measured. The information provided by three photodetectors (one specifically registering tristimulus value *x*, *y*, *z* each) enables the position of the incident light's color to be plotted within the color triangle.[5]

Silicon photodiode array has an integrated transimpedance amplifier that provides a low-impedance voltage source and widens the dynamic range of output signal. This facility enables the output signal to be monitored by either 4 - channel chart recorder or on the screen of an oscilloscope. It is a suitable means of eliminating the disadvantage associated with photoelectric type of colorimeter, which is technically complex and expensive. The silicon photodiode requires both an external power source and standard light source; it is a compact color measuring instrument that is less prone to overheating and is cost effective.[5]

ELECTRIC RECORDING SPECTROPHOTOMETERS [FIGURE 2]

These were used to measure the colors and the data were converted to Munsell notations. The concept was to measure the spectral reflectance of the different colors and convert them to numerical values. This was achieved by first determining the relative reflectance by comparing the samples to one with a known reflectance value. Absolute reflectance value and tristimulus co-ordinates (*x*, *y*, *z*) were derived from each absolute reflectance curve using (1931) the CIE standard observer functions and standard light source D 65. These values were then converted to corresponding CIELAB color system, and the color was determined through the difference calculated from each value.[8]

COMPUTERIZED SHADE MATCHING SYSTEMS[3]

This innovative technology improves the quality and predictability of treatment and saves time. Newer computerized instruments include the following:

Figure 2: Spectrophotometric measurement of a tooth

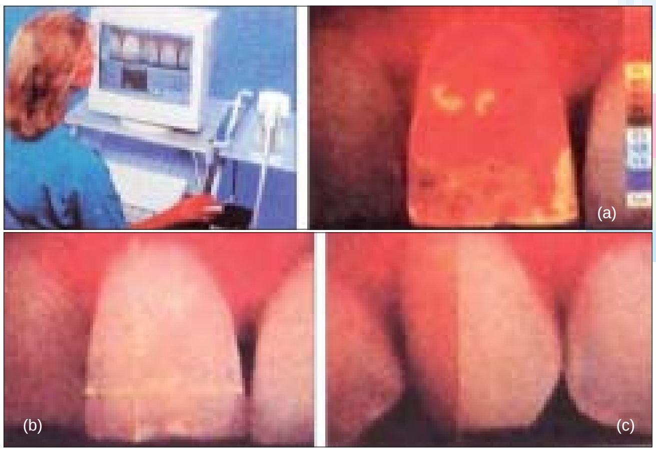

Figure 3: SpectroShade: (a) Mapping, (b) measurement, and (c) vertical split

SpectroShade [Figure 3]

The windows-based SpectroShade system utilizes dual digital cameras linked through optic fibers to a fully functional spectrophotometer. As the system precisely measures the color characteristics of natural tooth, it indicates the deviations of value, chroma and

Figure 5: Shade Eye NCC is a shade-taking computer with an integrated printer and a mobile measuring unit

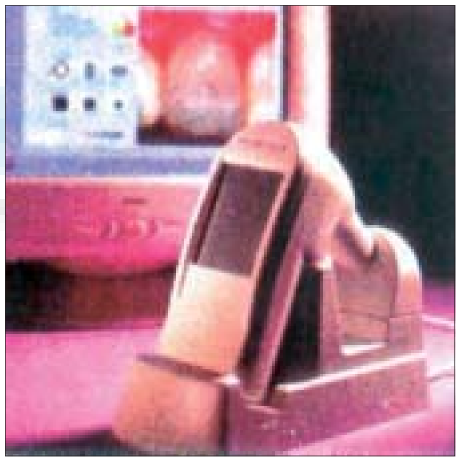

Figure 6: Shade-Rite measures hue, value and chroma and transforms the data into a digital format

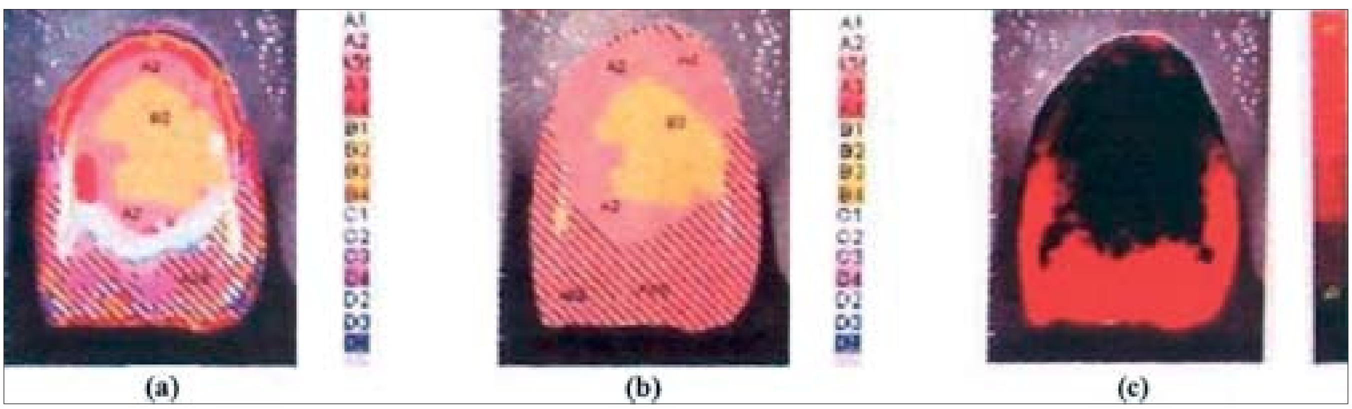

Figure 4: ShadeScan System: (a) fine-scale map (b) coarse-scale map, and (c) translucency image

hue from a standard, thereby providing information to modify the restoration and accurately match the tooth. The multifocal dual lighting mechanism illuminates the tooth in such a manner that the readings of its translucency and reflectivity are also taken, thereby allowing for shade measurements regardless of environmental lighting conditions. Dental images can be magnified, highlighted, rotated and measured. The split screen feature encourages the comparison of before and after images. It provides full face pictures on an intraoral camera, patient data (including images), spectral information, etc., stored on the 20 GB HDD hard drive, which is available for internet transfer to laboratory or can be transferred to a CD-ROM.

ShadeScan [Figure 4]

ShadeScan employs digital artificial vision technology with integrated CAD/CAM technologies. Shade is measured by a hand-held optical device from the single image of the entire tooth at the click of a button. Dentists can instantly obtain a shade map of the entire tooth with various established and popular shade systems. It generates a paint-by-numbers map of tooth, keying various areas of the dental surface to the selected shade guide by utilizing different resolution; the translucent and opaque areas are identified.

For the laboratory technician, differences in hue, chroma and value between natural tooth and shade guide ceramic are indicated by directing small color modifications. It identifies and highlights the markings on the tooth and indicates the surface texture. Images are available for electronic transmission to the lab by disk, or e-mail.

ShadeEye - NCC [Figure 5]

It consists of two components - a main unit that includes an integrated printer and a mobile measuring unit that is the size of a cell phone. The mobile wireless measuring unit analyses the tooth shade digitally and instantly transmits the information to the main unit through an infrared interface. It calculates the appropriate porcelain mixture. It visually eliminates disruptive factors such as the angle of viewing and position of the patient or dentist. The data, transmitted via disk or e-mail, can be processed on any PC/laptop. The technique involves the placing of a disposable contact tip in the gingival one-third of the tooth and then a color and shade map of the tooth is generated.

IKAM

IKAM combines the latest digital photographic technology and an innovative color analysis software. The color reference system of IKAM is based on actual fired ceramic samples rather than traditional shade guides, eliminating subjective interpretation.

Dentist selects the level of detail for each specific case - coarse (predominant shade), medium or fine (detailed analysis). Selected image level produces a shade map of the tooth. The digital camera captures two images of the tooth - glossy and matte. IKAM corrects the distortions by eliminating reflections so that the color underneath can be analysed. The data of the images is encrypted and transmitted to the lab via internet over to the internet to the laboratory. The software also guides the technician in choosing the proper combination of ceramic colors.

Shade-Rite [Figure 6]

This shade measuring device is handheld and portable, analyzing the shades of the tooth to be restored and the surrounding teeth with specialized imaging software. The cone-shaped sensor is pointed at the tooth to be replaced; the images are acquired, and it is replaced in its cradle. As the unit enters into the docking station, it initiates the system's software. The data is uploaded and software selects the most appropriate shades from the designated ceramic system, creating a prescription for the laboratory. The files are readily accessible and easily transmitted via the internet.

CONCLUSION

- An understanding of the science of color, color perception and their modification is important if success must be attained in the ever-expanding field of esthetic restorative dentistry.
- Colorimeters have been shown to be capable of providing reliable and reproducible tooth color measurements, removing potential variables found when the visual method is used.
- Electronic shade matching ensures accuracy, complete shade matching and the elimination of variables that tend to confuse and clutter the shade taking process. In effect, computerized shade matching puts the lab technician chairside.
- Although the human eye will be the final arbitrator, success in color construction and communication can best be achieved by combining traditional artistic techniques with the science of colorimetry.

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