



## A REVIEW ON DIGITAL SHADE MATCHING TECHNOLOGIES

## Dental Science

<b>Kalpana D</b>	Professor and Head of the Department, Department of Prosthodontics, Dayananda Sagar College of Dental Sciences and Hospital, Bengaluru, Karnataka, India.
<b>Smitha Sharan</b>	Reader, Department of Prosthodontics, Dayananda Sagar College of Dental Sciences and Hospital, Bengaluru, Karnataka, India.
<b>Sreeharsha T. V</b>	Reader, Department of Prosthodontics, Dayananda Sagar College of Dental Sciences and Hospital, Bengaluru, Karnataka, India.
<b>Brunda K.</b>	Senior Lecturer, Department of Prosthodontics, Dayananda Sagar College of Dental Sciences and Hospital, Bengaluru, Karnataka, India.
<b>Pradeep Chandra K.</b>	Senior Lecturer, Department of Prosthodontics, Dayananda Sagar College of Dental Sciences and Hospital, Bengaluru, Karnataka, India.
<b>Iti Badola*</b>	Post Graduate Student, Department of Prosthodontics, Dayananda Sagar College of Dental Sciences and Hospital, Bengaluru, Karnataka, India. *Corresponding Author

## ABSTRACT

The characterization and reproduction of tooth colour is a great challenge in dentistry. Esthetic expectations have exponentially increased over the last few years. Visual shade matching is a common method but varies depending on the clinician's colour perception and experience, ambient light condition, background of the tooth, and the shade guide used. Communication with a dental laboratory poses another problem which necessitates the use of digital methods for shade matching. If accurate this method could provide objective, quantified data. Hence, the aim of this article is to provide a comprehensive review of the current state of shade-matching technologies and instrumentation.

## KEYWORDS

Spectrophotometer, Colorimeter, Digital Software, Digital Camera

## INTRODUCTION

One of the main driving forces in dentistry today is the demand for aesthetic dentistry.<sup>1</sup> Prosthetic dentistry will only provide satisfactory results if dental restorations are esthetically pleasing.<sup>2</sup> Shade selection in dental practice is an important but difficult task. Dentists are challenged to satisfy the aesthetic requirement from patients when they select the shades to match the natural teeth during fabrication of prosthesis.<sup>3</sup> Thus, an accurate determination of tooth colour is crucial for obtaining a definitive result. In dentistry, achieving a colour match depends on a series of visual assessments that are usually communicated between two or more persons, typically the clinician, patient, and technician.<sup>2</sup>

Traditionally, shade selection has been performed visually with the aid of a shade guide. Various guides exist to facilitate the matching process however, regardless of the type of shade guide system used, visual shade determination is associated with a high degree of subjectivity. The ability to perceive colour differences varies from person to person and experience in shade matching may also be of importance. Furthermore, the performance may be affected by eye fatigue. The light source used when determining the shade has an impact on the appearance (metamerism) and could be a source of error as well. Therefore, a demand for methods that can analyze tooth shade objectively has emerged. This could result in greater reliability and thereby diminish the need for prosthesis colour corrections.<sup>4</sup>

Digital imaging has potential for use in dental shade determination.<sup>4</sup> The use of technology with different devices in shade selection may eliminate subjectivity of choosing and the use of photography to communicate shades and characterizations has improved the selection process.<sup>5</sup> Advances in electronic technology have provided solutions for many of the current problems in shade selection and colour matching in dentistry. Various digital methods for shade matching are:

- Spectroradiometer
- Monochromator
- Colorimeters
- Spectrophotometer
- Digital cameras
- Graphic Software

## Spectroradiometer

A spectroradiometer is used to measure the spectral power distribution

of the samples, and provides the ground truth for our colorimetry systems. To obtain an accurate radiometric measurement, it is necessary to remove the background contribution due to the dark current in the CCD array, and the unwanted light leakage in the experimental environment, and to calibrate the instrument along both the wavelength and the intensity axes. The background contribution is estimated by taking a measurement while the illumination is off.<sup>6</sup>

## Monochromator

A monochromator is an apparatus designed to provide a light source with a narrow-band spectral power distribution centered at a tunable wavelength.<sup>6</sup>

## Colorimeter

They provide measurements in CIELAB units ( $L^*$ ,  $A^*$ ,  $B^*$ ) that can compare the colour parameters of different objects when analysed mathematically. Colorimeters can be of two types: the photoelectric tristimulus colorimeters and silicon photodiode array.

Microcolour colorimeter (a photoelectric tri-stimulus colorimeter) is a self-contained measuring system that requires no external power source while a silicon photodiode array requires both an external power source and a standard light source; it is a compact colour measuring instrument.<sup>5,7</sup> Filter colorimeters generally use three or four silicon photodiodes that have spectral correction filters that closely simulate the standard observer functions. These filters act as analog function generators that limit the spectral characteristic of the light that strikes the detector surface.<sup>8</sup> It is because of their consistent and rapid sensing nature, these devices can be used for quality control.<sup>8</sup>



Figure1: Colorimeter

**Spectrophotometers**

A spectrophotometer measures and records the amount of visible radiant energy reflected or transmitted by an object one wavelength at a time for each value, chroma and hue present in the entire visible spectrum.<sup>5</sup> Consists of an illuminant source, a mechanism for dispersing light, a system to measure and convert the reflected light flux to a signal for analysis. The resultant colour measurements can be keyed to the various dental shade guides and converted to an equivalent of the respective shade tab.<sup>9</sup> They measure the amount of light energy reflected from an object's surface at 1-25nm intervals along the visual light spectrum (380-780 nm). Measures the amount of visible radiant energy reflected or transmitted by an object one wavelength at a time for each value, chroma, and hue present in the entire visible spectrum.<sup>9</sup> There are two basic optical light settings used in reflectance spectrophotometer instruments: Illumination at 0 degrees and observation at 45° (0/45) or illumination at 45° and observation at 0° (45/0). Because of the limited access afforded by the oral cavity, only the 45/0 option is suitable for clinical use.<sup>10</sup>

Handheld spectrophotometer for tooth shade matching contains a fiber optic tip is approximately 5 mm in diameter and nineteen 1 mm diameter fiber-optic fibers.<sup>10</sup> The device can be used to determine an overall tooth shade, the shade of each third of the tooth- cervical, middle and incisal, as well as to confirm the shade of the restoration.<sup>5</sup>



**Figure 2 : Spectrophotometer**

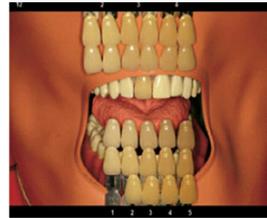
**Digital Cameras**

Digital photography, like many of the newer electronic technologies in the industry, offers significant benefits to dental practices. The digital camera is extremely efficient and easy to use.<sup>10</sup>

Photographs can be taken with an absolute dark or absolute white tab with 30° angled photos and a matching shade tab help a dentist to easily communicate with the laboratory technicians. By assessing these digital photographs, exact shade can be verified for the final result, eliminating shading errors and in turn excellent patient satisfaction.<sup>11</sup> Intraoral camera (Sopro 717) is a reliable assistance to visual colour assessment compared with conventional visual methods.<sup>12</sup> This LED lighting technology uses a 6500 K colour temperature and provides an enlargement of the tooth's image. In order to improve image quality, specially designed probe tips are used.<sup>13</sup> Intraoral camera with modified cross-polarization scheme are also used which block the light from outside, which can lead to shade-matching errors.<sup>2</sup>

They are based on the RGB colour model in which the camera obtains red, green, and blue data that is used to produce the colour image. In this additive colour model red, green, and blue light are added together to generate a broad arrangement of colours. Instead of focusing light on the film to create a chemical reaction, digital cameras capture images using charged coupled devices, which contain millions of microscopically small light-sensitive elements called photosites. Like the photodiodes, each photosite responds only to the total light intensity that strikes its surface. To get a full colour image, most sensors use filtering to look at the light in its three primary colors.<sup>8</sup> The highest-quality cameras use three separate sensors, each with a different filter over it. Light is directed to the different filter/sensor combinations by placing a beam splitter in the camera. The beam splitter allows each detector to see the image simultaneously. They provide a basic approach to electronic shade selection and require a degree of shade selection with the human observer.

The advantage of this method is that the camera records each of the three colours at each pixel location.<sup>8</sup>



**Figure 3: Shade Matching using Digital Photographs**



**Figure 4: Shade selection (intraoral anterior profile with 30° angulation)**



**Figure 5: Intra Oral Camera**



**Figure 6 and 7 : Intra Oral Camera with modified scheme**



**Figure 8: The Nikon Coolpix 990 digital camera with the chin rest mounted on a tripod.**

**Spectrophotometer+Digital camera**

The unit consists of a high-intensity halogen light source that is directed to the tooth through fiber-optic bundles and lenses to uniformly illuminate the field at a 45° angle.<sup>10</sup> The hand piece is relatively large compared with the contact probe designs, and positioning can be tricky. Calibration is a two-step process involving positioning the hand piece against white and green tiles. Light from a halogen source is delivered through fiber optic bundles and lenses to the tooth surface at 45°. The image of the tooth is displayed on the computer screen so that positioning can be verified. The incident light is monochromatic as it strikes the tooth, and as it is reflected back the spectral scanning process is completed at 10-nm bandwidths by a black and white and a colour-filtered CCD. Because there is a spectral curve associated with each pixel of the CCD, a significant amount of data are generated for analysis. Color differences can be calculated between compared images, and shade maps of increasing complexity and one for translucency are possible.<sup>8</sup> 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.<sup>14</sup>



**Figure 9: Spectrophotometer+ Digital Camera**

### Colorimeter+Digital camera

It consists of a hand-held device with its own light source, and an LCD screen facilitates positioning on the tooth. To focus and align the camera, a "glare spot" must be located at the junction of the gingival and middle thirds of the tooth. Measurements are taken through a series of rotating filters that simulate the CIE standard observer functions. The device is freestanding and is placed in its docking station for calibration and data transmission to the computer. Shade and translucency mapping, are possible, and colorimetric data (CIE  $L^*a^*b^*$  values) can be downloaded from the computer. The laboratory must have the required software.<sup>8</sup>



Figure 10: Colorimeter + Digital Camera

### Graphic Software

This is a software system that requires a Window platform PC and a digital camera. To properly calibrate the digital colour signal, a black and white standard and a shade tab must be included in each photograph. Detailed shade mapping is provided in shade guide designations, and standard and custom shade tab information can be entered into the system database.<sup>8</sup> The graphic software has the ability to analyse the image in terms of lightness (L), chroma (C), and hue (h) values. The internationally recognized CIE  $L^* C^* h$  colour system uses these colour values to objectively describe a colour. An area of the tooth is selected manually by the mouse pointer from the digital image and mean values of L, C, and h for the area are derived by software.<sup>4</sup> Digital images are taken after which the software is used to view and measure the colour of the shade tabs digital images. Image files are opened software. An area of 4 mm diameter is selected from the middle third of the digital image of the shade tab using the 'circle marquee' tool within the software (Adobe Photoshop). This area (4 mm diameter) is selected from the middle third of the shade tab tooth surface as it is found that this position could be reproducibly obtained on all the shade tab images. All digital colour measurements are made with the tooth in a central position within the monitor. The 'histogram' window within the software is selected to obtain average colour values of R, G, B of the selected area (4 mm diameter). These R, G B values are then converted to CIELAB colour coordinates using Colour Metric Converter software.<sup>15</sup>

To compare the shade guides the photographic images is transferred from the camera to a computer, saved as JPG files, displayed on a computer screen, and measured. A spot measurement for  $L^*$ ,  $a^*$ ,  $b^*$  (Commission Internationale de l'Eclairage  $L^* a^* b^*$  colour system) is then taken of each tooth of shade guide A from the computer screen images and recorded in the software to serve as a reference. Then  $L^*a^*b^*$  measurements are taken for each tooth of shade guide B images, the software automatically calculated the colour difference between shade guide A and B.<sup>16</sup>



Figure 11: Shade Matching done using Graphic Software

### CONCLUSION

The colour and appearance of teeth is a complex phenomenon, with many factors such as lighting conditions, translucency, opacity, light scattering, gloss and the human eye and brain influencing the overall perception of tooth colour.

The digital technology could provide an alternative accurate as well as cost effective method of tooth colour matching by enhancing communication with the laboratory personnel. The use of graphic software for quantitative colour determination may be an alternative to colorimeters and spectrophotometers. The method is relatively inexpensive, as digital cameras and computers are generally available in dental practices and laboratories. Instrumental methods appear to be a promising area for further research and are well suited in long-term observational studies. In spite of the limitations colour analysis of digital photographs has the potential to be used for shade matching in dentistry.

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