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# Methods for dental shade determination

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## ABSTRACT

Dental shade determination and seamless integration of restorative work in the oral cavity are challenging and important tasks in the everyday clinical dental practice. The aim of this *in-vitro* study was to evaluate comparatively the capability of software-based color analysis of mobile phone photography, with the spectrophotometric and visual methods for dental shade determination. Visual shade determination of the incisal, middle, and cervical thirds parts of ten extracted human teeth was performed using the Vita Classical and Vita 3D Master stock shade guides. Shade determination of the thirds of each tooth was performed using the Vita Easyshade spectrophotometer. Subsequently, photographs of each tooth were captured using a mobile phone camera. Color charts were produced using an in-house image processing technique, and the tooth color captured by the mobile phone photography was matched to the shade guides. The results show that the camera-based method had better agreement with the spectrophotometric and visual methods when the Vita Classical shade guide was employed. Software-based color analysis of mobile phone photography should be further explored for its use as an affordable potential tool for increasing objectivity and accuracy in dental shade determination.

**Keywords:** tooth color, shade selection, mobile phone photography, color maps, spectrophotometer, restorative dentistry

## 1. INTRODUCTION

Accurate dental color determination and communication is essential to enable esthetic integration of dental restorative work and to ensure patient satisfaction [1, 2]. Dental shade management is considered to be one of the most difficult challenges of restorative dentistry [2, 3]. Dental clinicians and technicians must be able to closely match natural teeth and create a lifelike imitation of tooth structure using restorative materials[3, 4]. This is challenging because natural teeth have great variation in color and many factors influence shade management in esthetic dentistry including light source, translucency, opacity, light scattering, and fluorescence [5]. In addition, color perception varies among clinicians [2]. Dentist-laboratory communication of subjective qualities in shade selection may lead to unwanted errors and subsequent remakes[3]. Despite advancements in protocols and technologies, shade matching in the anterior region remains a challenging task that often results in an unpredictable outcome. To minimize errors, reliable and objective shade determination and communication methodologies are needed [1, 3].

Traditionally, tooth shade matching can be approached through visual techniques using stock shade guides [5, 6]. The most widespread and popular shade guides in dental practice are the Vita Classical System (Vita Zahnfabrik) [7] and Vita 3D Master (Vita Zahnfabrik) [7]. The Vita 3D Master guide is arranged more systematically in the color space and studies have reported that the Vita 3D Master guide allows for superior shade matching [3, 6, 8]. Nonetheless, results of visual techniques using shade guides can be influenced by the examiner's experience and the environmental viewing conditions [8].

Instruments for tooth shade determination include spectrophotometers and colorimeters [8, 9]. Computerized colorimeters and spectrophotometers have been developed in attempt to overcome the shortcomings associated with the subjectivity of visual techniques using shade guides [9]. Vita Easyshade (Vita Zahnfabrik) is a popular instrument for spectrophotometric shade determination and has been found to be more accurate than colorimeters [10]. Previous studies have found that these

instruments produce consistent results but are not associated with higher accuracy than conventional visual methods using stock shade guides [1, 9, 11].

New techniques and technologies are emerging to enable more effective shade management [12, 13]. Recently, intraoral scanners have been implemented for shade management [13-15]. Digital shade management is a topic of interest that is continuously developing [1, 3, 13, 16]. The eLAB system has developed a standardized protocol for dental shade determination using digital camera photography [1, 3]. More studies are needed to determine the potential of mobile phone photography implementation in dental shade management [13].

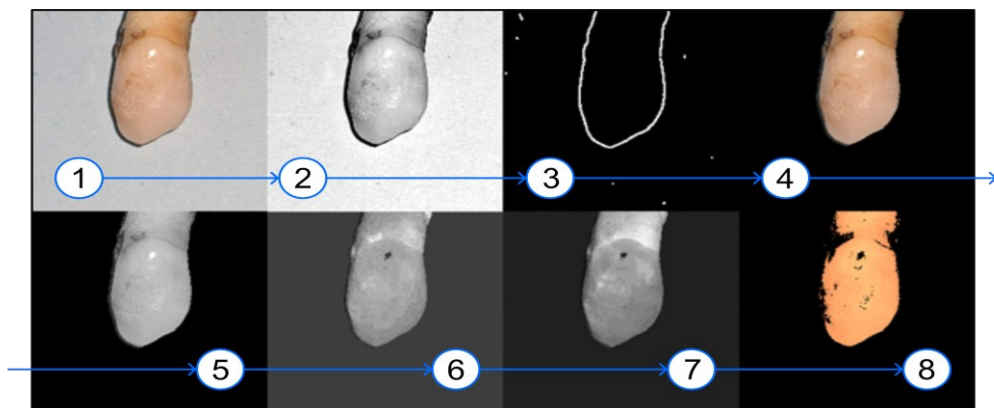
The aim of this *in-vitro* study was to evaluate comparatively the capability of software-based color analysis of mobile phone photography, with the spectrophotometric and conventional visual methods for dental shade determination.

## 2. MATERIALS AND METHODS

Ten extracted human teeth were obtained and stored in physiological serum. Each tooth was cleaned using running water and was evaluated visually using the Vita Classical (VC) and Vita 3D Master (V3DM) shade guide. Visual shade selection was conducted near a window using natural light and shade selection was performed for each tooth on the incisal, middle and cervical third. Then, each tooth was evaluated with the VITA Easyshade dental spectrophotometer. The spectrophotometer was used to identify the color of each tooth in the cervical, middle, and incisal thirds using the Vita Classical (VESC) and Vita 3D Master (VES3DM) shade scale settings. The identification of the colors has been performed (using all the techniques above) a number of 5 times for every individual tooth and area of interest.

High-resolution images of the teeth were captured using a mobile phone camera by placing them at an approximative distance of 10 cm from the camera's lens. The mobile phone camera was equipped with a single 12.2 MP standard array 1/2.55-inch sensor with 1.4 $\mu$ m pixels. For all situations, a flashlight has been used to uniformly illuminate the samples, however no other filters (such as polarisation filters) were used. Color charts of the regions of interest were produced using an in-house image processing technique. To generate the color charts, the following steps are used:

1. The original RGB (Red, Green, Blue) [17] image is converted into an enhanced grayscale image (image 2 in Fig. 1).
2. An in-house developed fast edge detection technique is employed to isolate the object of interest (the tooth). Once the tooth is isolated, it is displayed on a black background with all noise removed (image 3 in Fig. 1).
3. The RGB image is converted into CIELAB [18] which is a color space established by the International Commission on Illumination (abbreviated as CIE) . The three parameters of this color model ( $L^*$ ,  $a^*$  and  $b^*$ ) shown as examples in Fig. 1 (5, 6, 7) can be closely examined.
4. Based on the  $L^*$ -values, an image is mapped into a specific color-space (copper), that allows mapping to the color chart (image 8 in Fig. 1).



**Figure 1.** Procedure employed to build the colormaps of the teeth. 1: original image; 2: enhanced, gray-scaled image; 3: edge detection; 4: tooth extracted from the image; 5: L-map of the tooth; 6: a-map of the tooth; 7: b-map of the tooth; 8: color-mapped tooth (copper mapping) using the values of L.

### 3. RESULTS

Five images of each, the incisal, middle, and cervical areas of the ten teeth were taken and the technique described in the previous section was employed to generate the  $L^*a^*b^*$  values. As no filter was employed, on some occasions, the specular reflection of light off the enamel lead to  $L^*$ -values above those available in the shade guides, therefore they were displayed as 0-values in the  $L^*$ -maps and show as black spots in the image (as for example in Fig. 1(8)). In addition, due to the shape of the teeth and the relative position of the camera with respect to the teeth, slight variations of the  $L^*a^*b^*$  values from a pixel to another were obtained. As a result, averages of the  $L^*a^*b^*$  values were calculated across several regions of interest for each incisal, middle, and cervical areas of the tooth. The computations were done in such a way that the regions of interest considered avoided the areas where large values of  $L^*$  were produced. Data obtained for all ten teeth are summarised in Fig. 2.

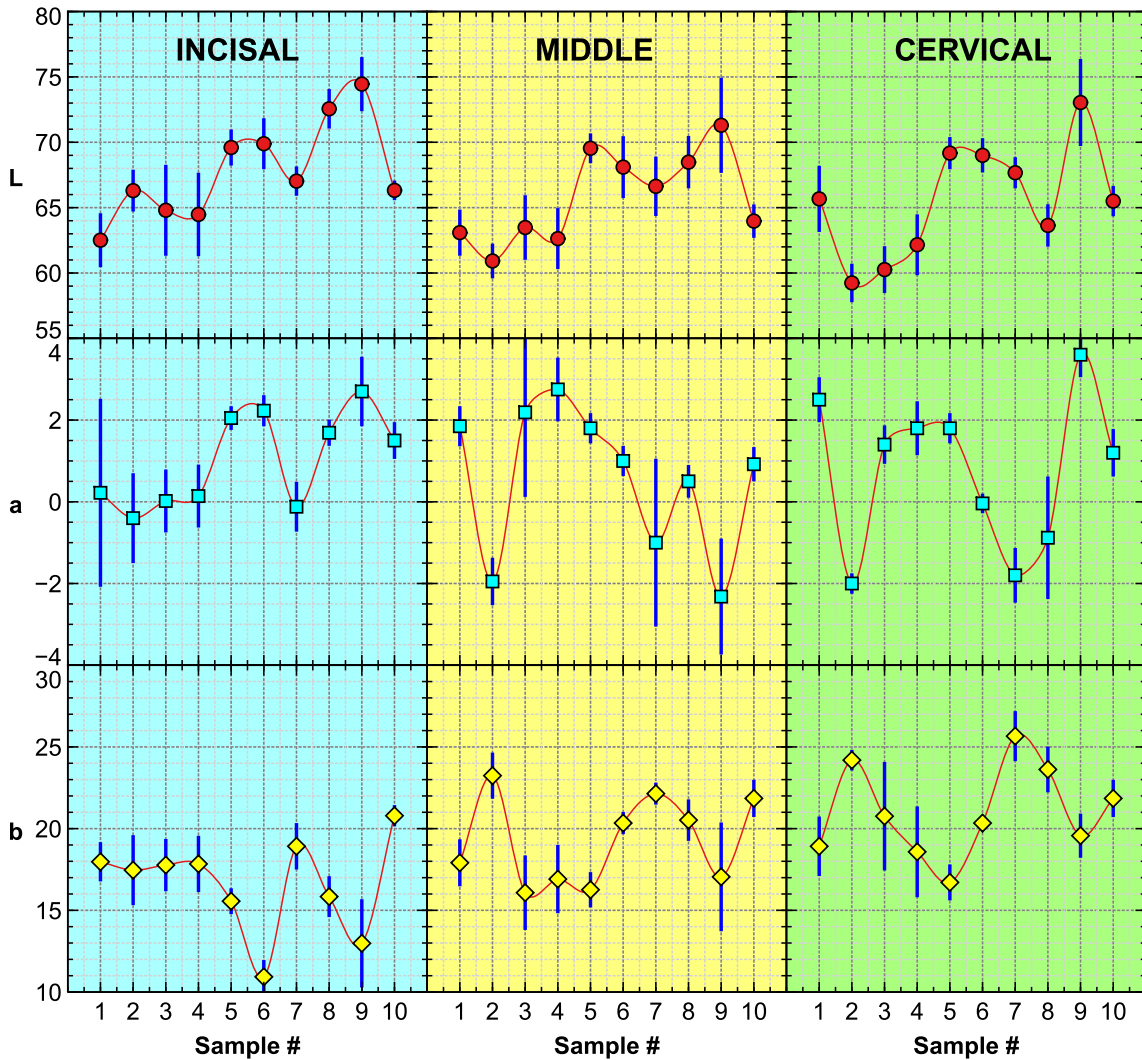


Figure 2.  $L$ ,  $a$ , and  $b$  values for each of the 10 teeth for the incisal, middle, and cervical areas. The blue vertical bars represent the standard deviations for each measurement set.

As illustrated in Fig. 2, as most of the numerical values of  $L^*$ ,  $a^*$ , and  $b^*$  fall within the range of the values employed by the Vita classical and Vita 3D Master shade guides, we used them to generate the corresponding shades based on our techniques. The CIELAB values obtained from the color analysis were converted to Vita Classical and Vita 3D Master shade guide values using Table 23.2 from Wee 2006 [19] and compared to the results obtained from the visual and

spectrophotometric methods. The Vita Classical shade tabs A1-D4 are grouped alphabetically (A, B, C, D) by hue and then further narrowed down numerically (ie. A1, A2, A3, A3.5, A4) in terms of chroma and value [18]. The Vita 3D Master categorizes the tooth color space in six lightness groups (0, 1, 2, 3, 4, 5). Each group has variations in hue (L, M, R) and value (1, 2, 3) [18].

In Figs. 3, 4, and 5 we present the shades determined by:

1. Spectrophotometric measurements employing the Vita Easshade spectrophotometer using the Vita Classic (VESC) and Vita 3D Master (VES3DM) shade scale settings.
2. Visual shades determinations, using VC (Vita Classic shade guide) and V3DM (Vita 3D Master shade guide)
3. Shade determinations using the procedure employing the camera of a mobile phone: CAM (Vita Classic shade guide) and CAM3D (Vita 3D Master shade guide).

Incisal	VESC	VC	CAM	VES3DM	V3DM	CAM3D
1	A3.5	A3.5	A3.5	4.5M3	3R2.5	3R2.5
2	A3.5	A3	A3	4M3	3M3	2R2.5
3	A3.5	A3	A3.5	5M3	3R2.5	3R2.5
4	A3.5	A2	A2	5M3	3M2	3R2.5
5	A2	A2	A2	1.5M2.5	1M2	1M2
6	A2	A2	A2	2M3	2M1	2M1
7	A3.5	A3.5	A3	3.5M3	4M3	3M1
8	B3	B4	A1	3L2	3L1.5	1M1
9	A3	B1	A1	3M3	2M2	1M1
10	A3.5	A3.5	A3.5	4M3	4M3	3M3

Figure 3. Shade determination using the Vita Classic and Vita 3D Master shade guides of the incisal area for each of the 10 teeth using three methods: spectrophotometric (VESC and VES3DM), visual (VC and V3DM) and digital camera based one (CAM and CAM3).

Middle	VESC	VC	CAM	VES3DM	V3DM	CAM3D
1	A3.5	A3.5	A3.5	5M3	3R2.5	3R2.5
2	A3.5	A3.5	A3.5	4.5M3	4M3	4M3
3	A3.5	A3.5	A3.5	5M3	4M3	3R2.5
4	A3.5	A2	A3.5	5M3	3M3	3R2.5
5	A2	B2	A2	1.5M2.5	1M2	2M1
6	A3	A2	A3	2.5M3	2M3	2M3
7	A3.5	A3.5	A3	4M3	4M3	3M3
8	B3	C2	B3	3.5L2	3L2.5	2M3
9	A3	B1	A1	2.5M3	2M2	2M2
10	A3.5	A3.5	A3.5	4M3	4M3	3R2.5

Figure 4. Shade determination using the Vita Classic and Vita 3D Master shade guides of the middle area for each of the 10 teeth using three methods: spectrophotometric (VESC and VES3DM), visual (VC and V3DM) and digital camera based one (CAM and CAM3).

Cervical	VESC	VC	CAM	VES3DM	V3DM	CAM3D
1	A3.5	A3.5	A3.5	5M3	3R2.5	3M3
2	A3.5	A4	C4	5M3	4M3	4M3
3	A3.5	A3.5	A4	5M3	4M3	4M3
4	A3.5	A2	A3.5	5M3	3M3	4M2
5	B2	B2	B3	1.5M2.5	1M2	2M2
6	A3	A3	A3	3M3	2M3	2M3
7	A3.5	A3.5	A3.5	4M3	4M3	3M3
8	A4	C3	A4	C3	3L2.5	3R2.5
9	B3	B1	A1	2.5M3	2M2	1M2
10	A3.5	A3.5	A3.5	4M3	4M3	3M3

Figure 5. Shade determination using the Vita Classic and Vita 3D Master shade guides of the cervical area for each of the 10 teeth using three methods: spectrophotometric (VESC and VES3DM), visual (VC and V3DM) and digital camera based one (CAM and CAM3).

All shades presented in tables on Figs. 4-6 are based on the average values generated by each individual technique. The cells with a green background shows agreement between cells across all three techniques, the blue cells show agreement on the shade between the camera-based method and either the spectrophotometric or visual techniques, whereas the red cells show situations in which there is no matching between the camera technique and the other two conventional methods. From these tables, it appears that the camera method produces shades closer to those obtained using the Vita Classical guide. 60-80% of the shades predicted by the camera technique matches at least one of shades determined by spectrophotometer and visual methods when the Vita Classical guide is employed, whereas when the Vita 3D Master shade guide is employed, only 30-50% of the shades matches the spectrophotometric/visual techniques.

#### 4. DISCUSSION

The camera-based method had moderate agreement with the spectrophotometric and visual methods when the Vita Classical shade guide was employed and low agreement when the Vita 3D Master was employed. The camera-based approach made use of the CIELAB color space which determined dental hue through  $a^*$  and  $b^*$  parameters and brightness through parameter  $L^*$ . Similar to the CIELAB mode, the Vita Classical shade selection process is based on hue and then further narrowed based on chroma and value. Since the Vita Classical shade selection process resembles very closely the CIELAB color model in its concept, this is likely the explanation of why the camera-based results provide a better match to visual and spectrophotometric methods employing this shade guide. For Vita 3D Master, the main distinguishing parameter is value, followed by further classification based on hue and chroma. To get better matching results with the methods employing the Vita 3D Master shade guide, an alternative approach in the algorithm of image processing could be taken, and this approach should imitate the VITA 3D Maser shade selection process. The value can be obtained immediately from the grayscale image, while the hue and chroma can be extracted from the image converted to the HSV (Hue, Saturation, Value) color space. Then, these three parameters (hue, saturation, and value) can be mapped to the Vita 3D Master shade guide tabs.

In this work, color maps were developed for individual teeth based on mobile phone photography. To obtain consistent results, calibration of mobile phone cameras would be a needed step in future studies. The software program requires input images of consistent spatial resolution and bit-depth. Calibration through the use of a test image can be used to solve this issue. The future development of a mobile phone application for dental shade determination could serve as an easy-to-use tool for dental shade management and an affordable alternative to costly spectrophotometers and digital camera photography protocols. Future studies using color analysis of mobile phone photography are needed to explore different color models, phone cameras, and effect of external conditions. Software-based color analysis of mobile phone photography should be further explored in order to allow for increased accuracy and objectivity of dental shade determination.

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