Reproducibility of a Digital Imaging Method for Measuring Tooth Color

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ABSTRACT

The use of a PhotoResearch spectrophotometer in conjunction with broad-source illumination has been shown to provide highly consistent *in vivo* tooth color measurements while reducing edge loss effects. However, this system provides results in numerical form only. With digital imaging, an image of the tooth is recorded, along with its numerical color value, facilitating the communication of results with fellow researchers. **Objective:** The objective of this study was to identify key sources of variation in a digital imaging color measurement system to assess the reproducibility in measuring *in vivo* tooth color. **Method:** Digital images of subjects' teeth were captured using a Fuji HC1000 CCD camera under broad-source lighting. The camera was positioned at a 45°/0° geometry with respect to the lights, and calibrated every hour with a standard color control chart. Color data were reported in CIEL*a*b* color space using Adobe Photoshop software. Twelve subjects were imaged over eight days, and the system was disassembled and moved to four different locations during this time. **Results:** The variance component for each source of variation and color value was estimated using the method of moments and is displayed in the table below.

Color Value	Mean	Estimated Variance Component for Source:					
		Location	Day Location	Subject	Location Subject	Msmt. Error	Total Variance
L*	68.7	0.18	1.53	24.94	0.21	1.41	28.27
a*	4.4	0.07	0.03	2.88	-0.01	0.13	3.1
b*	17.4	0.34	0.13	1.78	0.05	0.13	2.43

At alpha = 0.05, there were significantly greater than zero variance components for all sources except for location by subject. Differences between subjects' natural tooth color (Subject) was the largest contributor to the total variance while the contribution from all other sources was small. **Conclusion: This digital imaging system was found to provide high measurement reproducibility for assessing tooth color.**

INTRODUCTION

Reporting tooth color in CIEL*a*b* is an objective method for sharing color data, and colorimeters and spectrophotometers are common, well-known instruments used for this purpose. Shine, shadows and stain are just a few examples of information that can not be accurately conveyed with the numerical data reported from these instruments, but can affect the overall perception of tooth color to the human eye. Having a picture to accompany numerical data thus facilitates the evaluation of the observed tooth color. A high quality, digital color camera was chosen over conventional colorimeters because it provides a visual image as well as CIEL*a*b* color data. Combining the digital image with a computer software program, such as Adobe Photoshop, allows for the assessment of color uniformity over the entire image, or from any desired area of tooth or combination of teeth. For this study, a method for obtaining *in vivo* tooth color with a digital imaging system was evaluated for reproducibility and robustness. Key sources of variation with the measurement technique were also identified.

MATERIALS AND METHODS

The imaging system consisted of a metal frame which accomodated a chinrest/facebow to orient the subject's face, a Fuji HC1000 CCD camera and D55 broad source lighting using 4 dedolights. The camera was positioned at a 45°/0° geometry with respect to the lights. Distance from the lamp lens to plane of measurement was measured to be 31 cm. Voltage was measured at the output of the power supply and the input of each lamp using a voltmeter. Voltage was maintained between 12.2 and 13 volts. Crosshairs from a side digital camera and monitor were used to ensure consistent repositioning of the subjects' teeth in the plane of measurement. Color balance variation was corrected with the camera's white balance setup of camera, and a control chart with color tiles was also used for calibration. During the course of this study, the measurement equipment was disassembled and relocated to four different sites (two days at each site for 8 days total) to simulate the intended use of this system.

Panelists were instructed to maintain their normal eating patterns and oral habits during the panel, and asked to refrain from a dental prophylaxis. Panelists brushed with a wetted toothbrush before measurements were taken and used lip retractors for proper illumination. Measurements of the subjects' upper, left, central incisor were made, and the same area (# of pixels) was measured each time. These values were manually recorded in an excel spreadsheet, and the average and standard deviation calculated by the software program. A total of eight averaged whole tooth measurements per tooth were recorded for each subject.

RESULTS

The data were modeled using analysis of variance with random effects for location, day within location, subject, and all interactions with subject. Variance components for each of the random effects were estimated and expressed as part of the total variation. The results are displayed in Table I shown in the Abstract. The second column displays the mean color value from the digital image reading averaged over all subjects and visits. Columns 3-7 display the estimated variance component for the different sources in the ANOVA model: Location, Day within Location, Subject, Location by Subject, and Measurement Error. Note that the Measurement Error column gives the sum of two variance components: the Measurement Error variance component and the variance in repeat measurements of Subjects with the digital camera (where subjects are re-positioned for the replicates). Column 8 displays the total variation.

DATA ANALYSIS

Differences between subjects were the largest contributor to the variance while the measurement error contribution was small. Some variation was noted due to bulb age, temperature, or voltage variation. Color data for four color chips on the control chart showed very small variance relative to the subject teeth data (ie. 0.125 vs 28.27 for L*). This indicates that the lighting and digital camera are reproducible by themselves.

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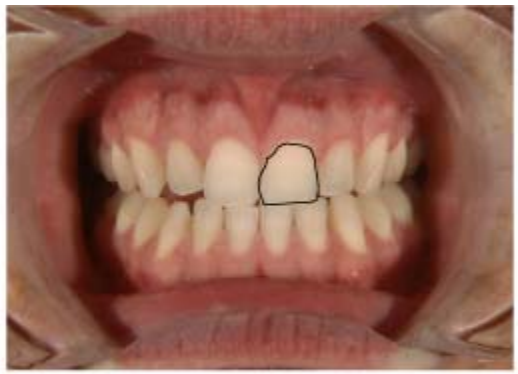
DATA ANALYSIS (cont.)

Thus the variance seen with the panelists is due either to the subject positioning or differences in actual tooth color each day. When the impact of individual subjects on the average was analyzed, it was found that subjects with mustaches contributed the most towards subject variance.

Measurement Possibilities with Digital Imaging

L*=79.23 a*=6.53 b*=17.09



L*=77.14 a*=7.21 b*=17.38

L*=74.02 a*=7.71 b*=18.52

CONCLUSION

This non-contact color measurement system which uses a high quality digital camera and broad-source illumination was found to be robust and reproducible in measuring intact human tooth color.

Main source of variation was subject positioning or actual change in tooth color.

More information can be obtained with the visual image vs. conventional colorimeters.

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