Designation: E2466 – 13

Standard Test Method for Colorimetry of Teeth Using Digital Still Camera Technology[1]

This standard is issued under the fixed designation E2466; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Tooth color is an important parameter used to ascertain certain medical and esthetic information. CIE colorimetric values for the teeth are derived from the native RGB signals generated by a digital still camera, DSC, by broadband measurement of the reflectance of teeth. The illumination angle is 45 degrees and CIELAB colorimetric coordinates are computed using equations contained in Practice E308. This test method, E2466, specifies the procedure used for the measurement of tooth color *in-vivo* and *in-vitro* with illumination at 45 degrees relative to the sample plane which is also the normal of the mouth, under an approximate equal energy spectrum. This test method is appropriate for anterior and posterior teeth.

1. Scope

1.1 This test method covers the procedure, instrumental requirements, standardization procedures, material standards, measurement procedures, and parameters necessary to make precise measurements of *in-vivo* tooth color and tooth whiteness. In particular it is meant to measure the color of teeth in selected human subjects.

1.2 Digital images are used to evaluate tooth color of both posterior and anterior dentition (teeth). All other non-relevant parts, such as gums, spaces, etc., must be separated from the measurement and the analysis. All localized discoloration; such as stains, inclusions, etc., may be separated from the measurement and the analysis.

1.3 The broadband reflectance factors of teeth are measured. The colorimetric measurement is performed with a digital still camera while using an illuminator(s) that provides controlled illumination on the teeth. The measured data from a digital image are captured using a DSC. This test method is particularly useful for the gamut of tooth color which is:

1.3.1 CIE L* from 55 to 95,

1.3.2 CIE a* from 3 to 12,

1.3.3 CIE b* from 8 to 25 units.

1.4 The wavelengths for this test method include that portion of the visible spectrum from 400 to 700 nm.

1.5 Data acquired using this test method is for comparative purposes used during clinical trials or other types of research.

1.6 This test method is designed to encompass natural teeth, artificial teeth, restorations, and shade guides.

NOTE 1—This procedure may not be applicable for all types of dental work.

1.7 The apparatus, measurement procedure, data analysis technique are generic, so that a specific apparatus, measurement procedure, or data analysis technique may not be excluded.

1.8 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D2244 Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates

E179 Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials

[1] This test method is under the jurisdiction of ASTM Committee E12 on Color and Appearance and is the direct responsibility of Subcommittee E12.06 on Image Based Color Measurement.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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E284 Terminology of Appearance
E308 Practice for Computing the Colors of Objects by Using the CIE System
E313 Practice for Calculating Yellowness and Whiteness Indices from Instrumentally Measured Color Coordinates
E1345 Practice for Reducing the Effect of Variability of Color Measurement by Use of Multiple Measurements
E1767 Practice for Specifying the Geometries of Observation and Measurement to Characterize the Appearance of Materials

2.2 *ISO Publications:*[3]
ISO 17321-1 Colour characterization of digital still cameras (DSCs) – Part 1: Stimuli, metrology, and test procedures

2.3 *ISCC Publications:*[4]
Technical Report 2003-1 Guide to Material Standards and Their Use in Color Measurement

3. Terminology

3.1 Terms and definitions in Terminology E284 are applicable to this test method.

3.2 *Definitions:*

3.2.1 Terms included in this section are peculiar to this standard.

3.2.2 *angle of incidence, n*—θ_1 and optional θ_2, the polar angle between the central ray of the illuminator(s), I_1 and I_2, and the Z axis which is normal to the camera. See Fig. A1.1.

3.2.3 *anterior teeth, n*—anterior teeth are the six upper and six lower front teeth; the anterior teeth consist of incisors and cuspids (canines).

3.2.4 *bit depth, n*—the number of digital bits used to store information contained in each pixel.

3.2.4.1 *Discussion*—The higher the depth, the more colors are in an image. With 8 bit-per-channel color, there are a total of 256 bits available for color representation in each of the R, G, B channels. RGB 8 bit-per-channel color is sometimes called "24 bit color."

3.2.5 *canine, n*—the third tooth from the center of the mouth towards the back of the mouth; these are the front teeth that have one rounded or pointed edge used for biting.

3.2.6 *facial surfaces, n*—of or toward the face, used to designate the side of the tooth that is facing away from the tongue side.

3.2.7 *in-vitro, adj or adv*—in an artificial environment outside of the human body.

3.2.8 *in-vivo, adj or adv*—within a living body; that is, measurements made of a living tooth in a living body.

3.2.9 *maxillary anterior teeth, n*—the four front upper incisors and the canine teeth. See Fig. A1.5.

3.2.10 *native digital still camera spectral response function, n*—the function relating scene radiance to image intensity of an imaging system is called the digital still camera spectral response function.

3.2.11 *polarization, n*—the orientation of the vibration pattern of light waves in a singular plane.

3.2.12 *polarizer filter, n*—a component that blocks one of the two planes of vibration of an electromagnetic wave, producing linearly polarized light.

3.2.12.1 *Discussion*—A polarizing filter can be used in sunglasses to reduce glare.

3.2.13 *posterior teeth, n*—posterior teeth are the large teeth in the back of the mouth.

3.2.14 *spatial whitening response, n*—the evaluation of color or color change used to determine unit dosing.

4. Summary of Test Method

4.1 This test method describes the procedures for broadband reflectance measurement of teeth, *in-vivo* and *in-vitro*. The standardization of the instrumentation used to measure a subject's teeth is defined. The basis for the selection of specimens and the measurement protocol given. The data from the reflectance measurements are converted to colorimetric values. The results are reported in terms of CIE tristimulus values, other colorimetric coordinate system values, and colorimetric indices.

5. Significance and Use

5.1 The light reflected from the facial anterior teeth can be used to calculate color coordinates. Monitored over time, changes in color can be observed. These data reveal information about the efficacy of a product, treatment study, or epidemiology of tooth color. For example, clinical studies of consumer tooth whitening systems evaluate the efficacy of manufacturers' products.

5.2 The change in color of the facial surfaces of anterior teeth can be used to optimize the efficacy of tooth whitening systems. For example, the data can provide the answer the question: "What is the optimum percentage of whitening agent in a consumer tooth whitening system?"

5.3 This procedure is suitable for use in research and development, marketing studies, comparative product analyses, and clinical trials.

5.4 Prior research shows that a popular visual assessment method of determining tooth color, changes in tooth color, and whiteness among clinicians yields less than desirable results (**1-4**). These assessment tools are designated "shade guides." They consist of tooth-shaped, synthetic objects in the form of teeth all of slightly different colors or different shades from one another. A "shade" is generally regarded as a color slightly different from a reference color (on a comparative basis). The colors of the synthetic teeth in these shade guides do not

[3] Available from International Imaging Industry Association (I3A), 701 Westchester Avenue, Suite 317W, White Plains, NY 10604, 914-285-4933, isotc42@i3a.org.

[4] Available from ISCC, Inter-Society Color Council, 11491 Sunset Hills Rd., Reston, Va, 20190, iscc.org.

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progress linearly as observed visually or logically in a CIE colorimetric coordinate system,[5] and they are metameric to real teeth.

5.5 *Translucency*—Human teeth are translucent and the degree of translucency varies widely between subjects. However, translucency does not vary over the short term and is not therefore a consideration in this test method.

6. Interferences

6.1 If the standard laboratory conditions listed in 6.2 change during the test or from test to test by an appreciable amount, these conditions may cause interferences, and the accuracy and precision requirements of this test method may not be achieved. In some cases these effects may only be observed during the performance of the test.

6.2 *Factors Effecting Test Results*—The following factors are known to affect the test results.

6.2.1 *Environmental:*

6.2.1.1 *Extraneous Radiation*—Extraneous light from other sources and near-infrared (NIR) radiations must be shielded from the test apparatus.

6.2.1.2 *Vibrations*—Mechanical oscillations that cause components of the apparatus to move independently from one another may cause errors in test results.

6.2.1.3 *Thermal Changes*—Temperature changes occurring during a test or differences in temperature between testing locations may affect the reflectance factor of the standardization, calibration, and verification plaques, and the apparatus spectral response function.

6.2.1.4 *Power Input Fluctuations*—Large changes in the line frequency or supply voltage may cause the apparatus to report erroneous results.

6.2.2 *Retractors*—The surface finish of the retractors affects the experimental test results. It has been determined that a neutral (clear) finish on the surface of the retractors may introduce a bias into the test results.

6.3 *Standardization*—The system must allow for successful standardization.

6.4 *Equipment Operation*—If the system cannot be standardized, a series of checks must be performed (lighting, camera, etc.) to identify the reason. The component of the system in error will be adjusted or replaced to bring the system back into calibration.

6.5 *Controlling Factors:*

6.5.1 These interferences may be eliminated and problems avoided by controlling and regulating each factor within the constraints of the allowable experimental error. The values and limits for these factors are typically determined experimentally.

7. Apparatus

7.1 *General*—The components described in this section are described generically. The intention is not to exclude any component from being used, or to exclude any type of instrument that may be available commercially. Between 4 and 6 different components or component assemblies are required to accomplish the measurement.

7.2 *Geometry*—The geometry of the system is 45:0 as described in Practice E1767 and Guide E179. The DSC System Geometry (Coordinate System) and Angular Convention are shown in Fig. A1.1.

7.3 *Components*—A block diagram of these component assemblies is shown diagrammatically in Fig. A1.2.

7.3.1 *Source Illumination Assembly*—Contains the source of illumination and associated optics to produce irradiance, *E*, on the sample over a specified spot area, designated *A*. The source is broadband and continuous in nature. A diagrammatic representation of the components of a typical Source Illumination Assembly Unit is shown in Fig. A1.3.

7.3.2 *Source Beam(s)*—A collimated or slightly converging beam(s) focused on the sample plane. Since the shape and position of the specimens being measured vary widely, a small convergence angle minimizes local variations in intensity. Two beams located at 45° relative to the normal of the sample plane are required to examine posterior teeth (on each side of the mouth) and to achieve the uniformity requirements.

7.3.3 *Position*—Typically the Source Illumination Assemblies are in a fixed position relative to the sample (Subject) holder and the DSC. Therefore, small variations in θ are minimized. The angle θ is the subtended angle between the Source Illumination Assembly Units and the DSC. Refer to Fig. A1.1.

7.3.4 *Source Optical Elements*—The optical elements must condition the radiation from the source so that it is spatially uniform within ±10 %. The distance, d, from the DSC to the sample plane must be selected to maintain the uniformity requirements. Refer to Fig. A1.6.

7.3.5 *Spectral Power Distribution*—The exact spectral nature of the illuminator is immaterial for the measurement of teeth and non-fluorescent specimens so long as the source is stable with time and has adequate energy at all wavelengths in the region required for measurement. An approximation to D50 provides an equal energy spectrum over the area of interest for DSCs. Commonly used light sources include incandescent lamps, either operated without filters or filtered to simulate standard illuminants, flashed or continuous-wave xenon-arc lamps and discrete pseudo-monochromatic sources, such as light emitting diodes (LEDs).

7.3.6 *Polarization*—The linear polarizer provides and controls the polarization state of the incident light. This polarizer on the illuminators plus a cross polarizer filter on the lens system of the DSC eliminates glare caused by reflection of the subject's teeth during imaging. Wavelength range, extinction ratio, transmittance, and beam deviation are important parameters and must be selected.

7.3.7 *Heat Rejection Filters*—These filters remove undesired near-infrared (NIR) radiation including heat that adversely affects the subject and provide spectral shaping of the spectral power distribution of the source illumination.

7.3.8 *Selective Blue Filters*—These filters condition the spectral power distribution of the illuminator so that the

[5] Available from University of Michigan, http://www.lib.umich.edu/dentlib/Dental_tables/Colorshadguid.html.

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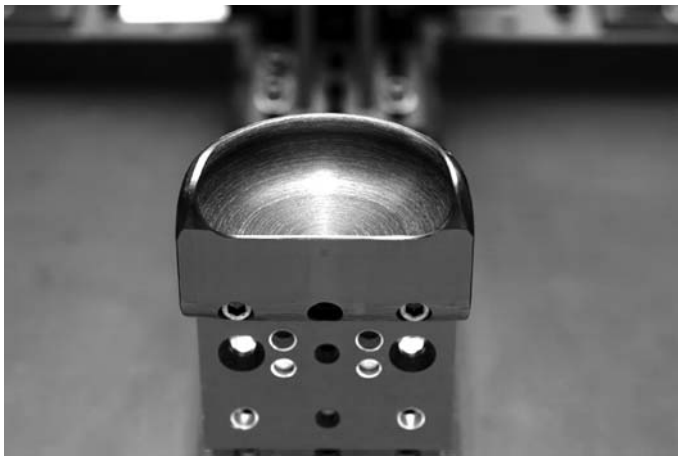

FIG. 1 Chin Rest

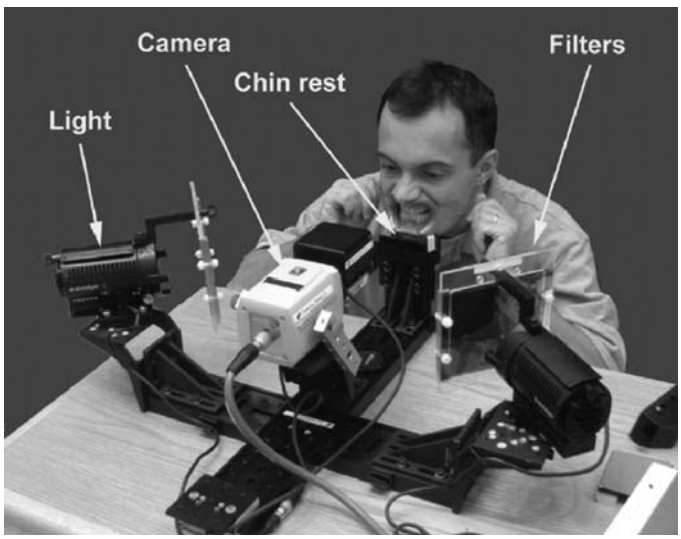

FIG. 2 Subject Positioned in Instrumentation

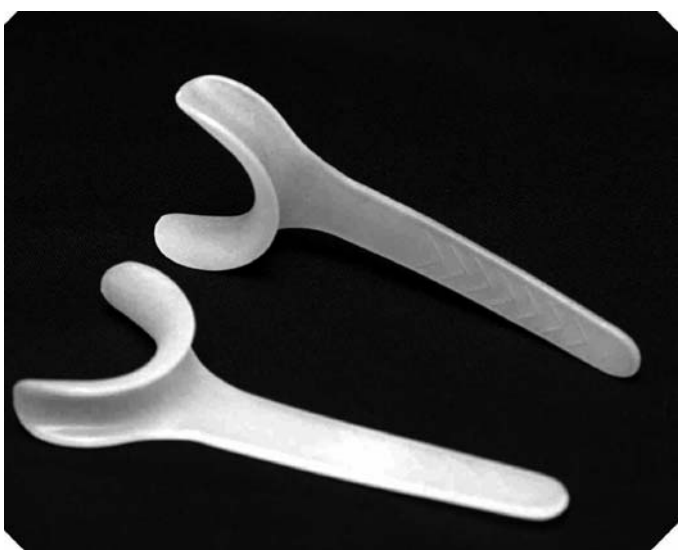

FIG. 3 Matte Lip Retractors

spectral power distribution is similar to an approximate equal energy spectrum, such as illuminant D50.

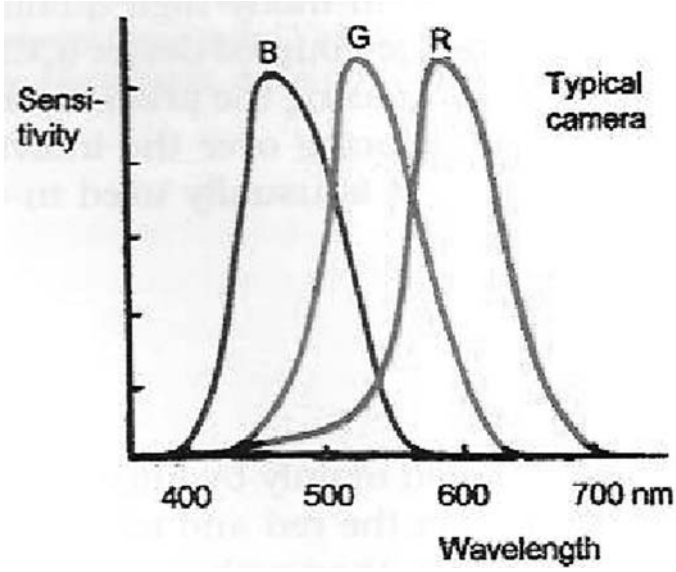

FIG. 4 Typical DSC Native Spectral Response Function

7.4 *Sample Plane Holder*—The sample plane holder provides a secure mount so that it positions the subjects incisors normal to the Z axis and centered along the X and Y axes. This must be done so that the teeth are presented to the DSC in a repeatable and reproducible manner. The sample mount must be kept unobtrusive so that it is "friendly" and not intimidating to the subjects. A chin rest is used to precisely position the subjects relative to the instrumentation. The subjects place their chin on a chin rest which is a quarter-cup shaped rig, as shown in Fig. 1. Fig. 2 shows a subject correctly positioned in the instrument for measurement. Lip retractors,[6] as shown in Fig. 3, are used to expose the majority of the subject's teeth and gingiva to the DSC system. Subjects hold their head straight, join the tips of their upper and lower incisors together and place their tongue against the top of their mouth.

NOTE 2—Some people cannot do that, so they might keep a space between their teeth.

The facial surface of the central incisors should be aligned with a line marked on the chin rest indicating the center along the X axis.

7.5 *Detector Optical Elements:*

7.5.1 The typical detector optical elements are shown in Fig. A1.4 included in Annex A1.

7.5.2 The linear cross polarizer provides and controls the plane of polarization or the E-vector of the electromagnetic wave. This linear cross polarizer eliminates unwanted reflection of the subject's teeth during imaging. The linear cross polarizer must be rotated around the optical axis of the beam to change the plane and state of polarization; therefore eliminating the strong reflection caused by the wetness of teeth during measurement. This cross polarizer must be oriented perpendicular, 90°, to the Source Polarizing elements. The linear cross polarizer assembly is shown in Fig. A1.4.

[6] Retractors with a matte finish have been found satisfactory for this purpose.

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