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Dentistry — Guidance on colour measurement

Médecine bucco-dentaire — Directives relatives au mesurage de la couleur

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Foreword

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Introduction

The colour appearance of teeth and other dentistry-related tissues needs to be matched and reproduced in order to achieve acceptable aesthetics in an efficient manner. Three major groups of issues, related to colour compatibility, colour stability and colour interactions, are identified and considered in this Technical Report. Interpretation of colour differences associated with these three groups through 50:50 % perceptibility and acceptability visual thresholds is suggested. Colour is a psychophysical phenomenon that is assessed by both visual and instrumental methods. Other elements of appearance, including gloss and translucency, affect aesthetics and may influence the characterization of colour appearance.

The International Commission on Illumination (CIE) colour difference formulae and resources, in particular CIE Pub No 15.3, were used in this Technical Report.

Dentistry — Guidance on colour measurement

1 Scope

This Technical Report identifies three types of topics related to shade conformity and interconvertibility of monochromatic and polychromatic tissues and materials related to the discipline of dentistry; it describes visual and instrumental methods for assessment of these topics.

This Technical Report suggests interpretation of the findings through colour difference thresholds, and provides guidelines for future standardization related to dental shade conformity and interconvertibility. It also includes guidelines related to colour vision of persons undertaking visual colour assessments and instructions for reporting of colour and colour difference assessments.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1942, *Dentistry —Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1942 and the following apply.

3.1
colour difference
single number or metric expressing the distance from complete match in colour or shade

NOTE 1 A colour distance metric defined by the International Commission on Illumination (CIE) is called delta E (ΔE).

NOTE 2 Two formulae for calculating ΔE are recommended in this Technical Report: CIE76 (denoted ΔE^*_{ab}) and CIEDE2000 (denoted ΔE_{00}).

3.2
50:50 % perceptibility threshold of colour difference
PT
difference in colour that can be detected by 50 % of observers, with the other 50 % of observers noticing no difference in colour between the compared objects

NOTE A nearly perfect colour match in dentistry is a colour difference at or below the 50:50 % perceptibility threshold.

3.3
50:50 % acceptability threshold of colour difference
AT
difference in colour that is considered acceptable by 50 % of observers, with the other 50 % of observers replacing or correcting the restoration

NOTE An acceptable colour match in dentistry is a colour difference at or below the 50:50 % acceptability threshold.

3.4
colour standards in dentistry
sets of polychromatic or monochromatic samples (tabs, chips, or patches), most frequently made of dental ceramic or resin (tooth shade guides), or silicone elastomer (skin shade guides in maxillofacial prosthodontics)

NOTE The polychromatic and monochromatic samples are fabricated for the purposes of colour matching hard and soft oral tissues, and human skin (see Reference [2]).

3.5
coverage error
index that describes the minimal colour differences (ΔE^*_{min}) between the specimens of one set (e.g. a shade guide) to each specimen of another set (e.g. natural teeth)

NOTE The coverage error is calculated as the mean ΔE^*_{min} for all best matches as follows:

Coverage error = $\Sigma \Delta E^*_{min}/n$

Where n is the number of best matches.

The smaller the coverage error, the higher the chances of successful shade matching.

3.6
tooth whitening
change in tooth colour caused by bleaching or stain-removal agents and manifested by the increase in the value of lightness and the decrease of chroma

3.7
colour shifting
change in perceived colour that is a sum of a blending effect and an effect of physical translucency

3.7.1
colour shifting due to blending
change in perceived colour of a material due to a change in surroundings

NOTE Colour shifting due to blending is a psycho-physical phenomenon, and is not modelled by the current CIELAB mathematical model; it is an optical illusion — visually perceptible, but not currently quantifiable or measurable by any instrument.

3.7.2
colour shifting due to physical translucency
change in colour of translucent dental restorations caused by surroundings and background (underlying layers of hard dental tissues or other restorative materials)

3.8
opacity
measure of the ability of a material to block the passage of light

NOTE A material with high opacity is one with low translucency/transparency.

3.9
transparency
physical property of allowing the transmission of light through a material

NOTE 1 A material with high transparency is one with low opacity.

NOTE 2 Transparency is the extreme value of high translucency.

NOTE 3 A transparent material allows light to pass through undiminished, while a negligible portion of the transmitted light is scattered.

3.10
translucency
ability of a material to allow light to pass through it

NOTE 1 A material with high translucency is one with low opacity.

NOTE 2 Translucent materials allow light to pass through only diffusely (they cannot be seen through clearly).

3.11
gloss
capacity of a surface to reflect more light in some directions than in others

3.12
specular gloss
ratio of flux reflected in the specular direction to incident flux (i.e. the angle of the reflected light is equal and opposite to the angle of the incident beam) for a specified angle of incidence, source, and receptor angular aperture

NOTE These reflections normally have the highest reflectances (see References [2] and [3]).

4 Visual and instrumental colour assessment

4.1 Devices

Frequently used devices for visual and instrumental colour assessment in dentistry are spectrophotometers, spectroradiometers, colourimeters, imaging systems for traditional digital imaging and spectral imaging, viewing booths, and different types of hand-held shade matching lights.

Spectral measurement is performed using a spectrophotometer, a device designed to measure spectral transmittance and spectral reflectance factor of objects. Compared to colorimetric measurements, spectral measurements enable more flexible measurements to calculate color differences under arbitrary illuminants and observers.

Spectrometer parameters relevant for dentistry include wavelength range, wavelength resolution, integration time and spectral sensitivity. In addition to these parameters, method of measurement, technology and geometry have to be taken in account when selecting the equipment or designing a system to measure spectra.

Spectral measurement accuracy can be measured in terms of root mean square error (rms) or degree of correlation between spectral data, and other weighted spectral measurements that emphasize the wavelength that are more relevant for human vision. Having spectral measurements of both reference and test samples it is possible to calculate how robust is the pair of samples to changes in illumination and observers by means of index of metamerism.

4.2 Setting

Colour assessment requires careful control of factors that affect colour perception and/or measurement. The following aspects of the test conditions should be specified in reporting visual assessments of colour appearance.

4.2.1 Illuminant

The characteristics of the light source or sources that illuminate the object of a colour measurement as specified preferably by the spectral power distribution (SPD) and correlated colour temperature (CCT)

specified according to ISO 11644-2:2007. CIE standard illuminant D65 (representing noon daylight, CCT of 6500 K) with a Colour Rendering Index (CRI) of 90 or greater is recommended for visual colour measurements in dentistry.

4.2.2 Standard observer

The 2° 1931 standard observer as defined in ISO 11664-1:2007 should be used for teeth and dental restorations. The 10° 1964 supplementary standard observer, also defined in ISO 11664-1:2007 should be used for larger measurement areas, such as oral soft tissues and skin.

4.2.3 Geometric conditions

The optical geometry of a measurement is defined by the angle of illumination and the angle of viewing relative to the surface of the object. It is expressed as illumination geometry/viewing geometry. CIE recommends different types of optical geometries in reflection, including 0°/45°, 45°/0°, d/0° and 0°/d-based geometries that are most suitable for visual colour assessments in dentistry (where *d* denotes diffuse). Optical geometries that are associated with the use of integrating sphere are related solely to instrumental measurements.

4.2.4 Illuminance

The total luminous flux incident on a surface is a measure of the intensity of the incident light (lumens/area). Illuminance is measured in lux (lx). The foot-candle is a non-metric unit of illuminance (used in photography).

NOTE An Illuminance of 1 000 lux is considered optimal for visual colour assessments.[4]

4.2.5 Visual angle of subtense[4]

The visual angle of subtense (2Θ) is calculated from the size of the object r and its distance d from the observer as: $2\Theta = 2 \arctan (r/d)$.[4]

NOTE In visual assessment, larger sizes increase visual precision. A visual angle of subtense is not less than 2°.

4.2.6 Background

The background is defined as the surface upon which samples are placed; the environment of the stimulus, extending for about 10° from the edge of the stimulus in all, or most, directions.

4.2.7 Surround

The surround is defined as the field outside the background. In practical situations, the surround can be considered to be the entire environment in which the stimuli are viewed.[5] The surround should be matte and neutral (grey).

4.2.8 Additional/other considerations

See Reference [1] for the additional consideration on the topics mentioned in this clause and on other related topics, such as spectral measurements and calculation algorithms, specular component, metamerism, whiteness index, and yellowness index.

5 Observers

5.1 Evaluation of colour competency of candidate for observer in studies on acceptability or perceptibility in dentistry

5.1.1 Ishihara colour blindness test

The Ishihara Colour Blindness Test[6] is a test for red-green colour deficiencies. It consists of a number of coloured plates, each of which contains a circle made of many different sized dots of slightly different colours, spread in a seemingly random manner. Within the dot pattern, and differentiated only by colour, is a number. The full test consists of thirty-eight plates, but the existence of a deficiency is usually clear after several plates.

5.1.2 Farnsworth-Munsell 100 hue test

The Farnsworth Munsell 100 Hue Test[7] has been used for many years as a definitive standard for testing colour discrimination - the ability to discriminate between various shades of a given colour. The test will determine if the observer is superior, average or poor at discriminating colour.

5.1.3 Test for colour discrimination competence in dentistry

Test subjects should match pairs of shade guide tabs. One set of tabs should have original markings on tab holders (such as A1, B1, 1M2, 2M2, or similar) while the original markings of the other set of tabs should be covered with custom letters, numbers or symbols (such as A, B, 1, 2, or similar). Visual comparisons should be made under the D65 illuminant of a viewing booth (the overhead lights should be turned off), at the distance of 25-33 cm, using 0°/45° or 45°/0°optical geometry. Tabs should be removed from joint tab holders, placed on the floor of the viewing booth and mixed. After a period of adaptation by observing the walls of the viewing booth, the observers should begin tab arrangement. At least twelve pairs should be matched and one point should be assigned for each correctly matched pair. The test can be repeated with at least 7-day interval between the tests, in which case the higher of the two scores will be counted.

5.2 Guidelines for observer selected for acceptability or perceptibility evaluation in dentistry

5.2.1 General tests

All potential observers should undergo either Ishihara test – the results should demonstrate normal colour vision), or Farnsworth-Munsell 100 hue test – the results should demonstrate superior or average colour discrimination.

5.2.2 Test for colour discrimination competency in dentistry

In order to be considered competent for colour matching in dentistry, an observer should have correctly assigned at least 60%, 75% and 85% of the sample pairs presented in the test (see 5.1.3) for poor-, average-, and superior colour discrimination competency, respectively. At least 20 observers with superior- and average colour discrimination competency should participate in evaluation of perceptibility and acceptability visual judgments in dentistry, including at least 50% of dental professionals. Quality control and other visual colour evaluations should be performed by at least 3 observers qualified as having superior colour discrimination competency according to 5.1.2 and 5.1.3.

5.2.3 Testing intervals for qualified observers

The time interval between passing the tests for colour discrimination as described above and the observation activity should not exceed twelve months.

6 Testing of acceptability and perceptibility thresholds

Visual assessments of perceptibility and acceptability are performed for research, quality control and related purposes. Perceptibility judgment studies typically consist of subjects answering the question “Can I see a difference in colour?” These judgments are associated with detecting just-perceptible differences and they do not involve any interpretation of their importance.[4] These differences are usually small compared to what would be considered acceptable colour difference in a given industry. The colour difference acceptability can be determined by asking an additional question “Is this difference in colour acceptable?” Therefore, colour tolerance for a certain product is the just-perceptible difference increased by a commercial or aesthetic factor.[4]

Both visual and instrumental evaluations are necessary to determine colour difference thresholds in dentistry and they should be performed in compatible settings. Perceptibility and acceptability visual judgments should be performed under both in-vitro conditions and in clinical conditions.

6.1 Materials to be tested for perceptibility and acceptability thresholds

Dental restorative materials are coloured to match a) teeth, b) oral soft tissue and c) skin.

6.2 Test methods

6.2.1 Visual judgments

Devices and settings described in Clause 4 should be used. Visual comparisons should be made in a viewing booth with non-booth lighting turned off, in (simulated) clinical setting, or both, depending on the goal of the study.

6.2.2 Instrumental evaluation

Devices and settings described in Clause 4 should be used.

7 Application and interpretation

The following thresholds can be applied to all issues related to quality of colour matching in dentistry. Interpretation of the results is based on tests performed using defined conditions and methods.

7.1 Colour compatibility

7.1.1 Colour compatibility between dental material and human tissues

If the colour difference is at or below the perceptibility threshold (PT), it represents a very good match; if this difference is between PT and acceptability threshold (AT), it represents an acceptable match; if this difference is above the AT, it represents an unacceptable match.

7.1.2 Colour compatibility between dental materials

If a colour difference between nominally equivalent shades of similar dental materials/shade tabs made by the same or a different manufacturer is at or below PT, it represents a very good colour compatibility; if it is between PT and AT, it represents an acceptable compatibility; if it is greater than AT, it represents an unacceptable compatibility.

7.1.3 Coverage error of dental shade guides

If the coverage error of dental shade guide is at or below the AT, it represents an excellent product; if the coverage error is between AT and AT + 2.0 ΔE^*_{ab}[9],[10][11], it represents an acceptable product; if the coverage error is higher than AT + 2.0 ΔE^*_{ab}, it represents an unacceptable product.

7.2 Colour stability

7.2.1 Colour stability during fabrication/at placement

If the colour difference during fabrication (firing, glazing, polymerization, or other types of preparation) or at placement is at or below the PT, it represents an excellent colour stability; if this difference is between the PT and AT, it represents an acceptable colour stability; if this difference is above the AT, it represents an unacceptable colour stability.

7.2.2 Colour stability after aging and staining[8]

If the colour difference measured before and after aging or staining is at or below the PT, it represents an excellent match; if this difference is between the PT and AT, it represents an acceptable match; if this difference is above the AT, it represents an unacceptable match.

7.3 Colour interactions

7.3.1 Colour shifting of aesthetic restorative materials[12],[13]

Colour shifting of aesthetic restorative materials is the change in perceived colour that is a sum of the blending effect (not-measurable by any instrument, optical illusion) and the effect of physical translucency. For the purpose of this report and corresponding comparisons the colour difference between two objects, one surrounded with another or in edge-contact should be between ΔE^*_{ab}=2.0 and ΔE^*_{ab}=5.0.

Visual assessment: If the perceived colour difference between tested material and another material surrounding it receives a grade that is 20% higher on 1-to-5 scale (1. mismatch/totally unacceptable; 2. poor match/hardly acceptable; 3. good match/acceptable; 4. very good match/small difference; and 5. exact match/no difference in color) compared to the grade received when they are viewed in isolation, the material exhibits low colour shifting potential; if this increase is in grade is 20-50%, the material exhibits moderate colour shifting potential; if the increase is above the 50%, the material exhibits pronounced colour shifting potential.

Instrumental measurements: If colour difference between tested material and another material surrounding it decrease up to 15% compared to the measurement of specimens of test material (without the second material), the material exhibits low colour shifting potential; if this decrease is between 15-25%, the material exhibits moderate colour shifting potential; if this decrease is greater than 25%, the material exhibits pronounced colour shifting potential.

7.3.2 Masking potential of opaque materials

If the translucency parameter (colour difference between the same specimen measured against white and black background) of 1-mm thick opaque composite resin[14] and 0.3 mm-thick opaque porcelain[15],[16] is at or below PT, it represents an excellent masking potential; if this difference is between PT and AT, it represents an acceptable masking potential; if this difference is above AT, it represents an unacceptable masking potential.

8 Reporting of colour and colour difference assessment[17],[18]

When applicable, a report of a colour assessment should contain or refer to the following details:

8.1 Illuminant

a) type

b) manufacturer

c) spectral power distribution

d) correlated colour temperature

e) colour rendering index

f) illuminant geometry

g) illuminance

8.2 Object

a) type of object (tooth, soft tissue, dental material)

b) type of colouration (monochromatic or with colour transition

c) size

d) placement of standard and trial when comparing colour (side by side or other placement)

e) standard distribution, usage, storage, maintenance, and replacement (shade guides and other standards)

8.3 Observer/Instrument

8.3.1 Observer

a) number of observers

b) colour competency

c) viewing geometry

d) distance from object to detector or observer

e) visual angle of subtense of the object

f) colour of background and surround

8.3.2 Instrument

a) type (spectrophotometer, spectroradiometer, colourimeter, imaging system)

b) manufacturer

c) model number

d) instrument number

e) instrument accuracy and precision

f) measurement mode: reflectance or transmittance