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Comprehending Color Science and Shade Matching Along with its Application in Dentistry: A Narrative Review

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KEYWORDS

color, visible light, shade guide, metamerism, Munsell system, depth

ABSTRACT:

Knowledge of light and its perception as color is a topic of interest, that imparts a depthwise information , based on which the art of cosmetic dentistry thrives. Starting from three dimensional components of color i,e hue, value and chroma to its interpretation via visible (eye) as well as instrumental technique, provides a way of depicting the realness and depth in fabricating the artificial teeth. This review article attempts to emphasise in details the factors such as optical properties of light, illusion, techniques of shade matching, limitations associated with various techniques, as well as the importance of laboratory communication with the technicians.

1. Introduction

Color is an optical phenomenon which is characterised by psychophysical sensation that results when the human visual system responds to the light reflected from objects on a scene. The eye perceives and the brain interprets light as color. According to GPT 8 color is defined as the phenomenon of light or visual perception that enables one to differentiate otherwise identical objects. A visual response to light consisting of three dimensions i,e hue, value and saturation.[1] Esthetics in dentistry requires the artistic skill of managing interplay of light through a property called illusion. It is the ability of the dentist to see the unseen through his experience and implement the illusion to mimic reality. In cosmetic dentistry, clinical success for dentists is to choose the accurate shade of a tooth color and apply the closely matched quality material. [2] Communication with the lab technicians is important to achieve good esthetic results.[3]

In the field of dentistry, an understanding of the nature of light and color science is important for successful esthetic fabrication of metal-ceramic or all-ceramic restorations. The effect of tooth shade is achieved by the combination of intrinsic and extrinsic colorations. Intrinsic coloration is related to the light scattering and properties of absorption by the enamel and dentin. Extrinsic coloration is linked with material absorption onto the surface of enamel and specifically, the pellicle deposition (e.g., red wine, tea, iron salts and chlorhexidine).[4]

2.Aim of the study: The purpose of this review of the literature is to analyze the accurateness of color matching using different shade-selection techniques.

3. Visible light

Electromagnetic waves are of varied nature ranging from radiowaves, microwave, infrared, ultraviolet (UV), xrays, and gamma rays. These cannot be perceived by the human eye,and belongs to the “invisible” spectrum. Electromagnetic waves are present everywhere and visible light comprises a part of it.[5] Light is a form of energised photons that move as waves.Light is perceived through human eye as white light, more precisely “visible” light (380 nm to 780 nm). The visible and invisible spectrums together forms the electromagnetic spectrum **(Figure 1).**

The light visible to the naked eye is not white. The white effect of light is combination of all the colors of the rainbow - red, orange,yellow,green,blue,indigo and violet. In the year 1676, Sir Issac Newton with the help of a prism made the white light pass through it. While transmitting through the prism the course of light bends, and each wavelength changes direction by a different

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amount rendering the visibility of respective individual colors, percievable to the naked eye **(Figure 2).** While passing through a media, light can be reflected, absorbed, or transmitted. If the light entirely reflects, the object appears white. If the light is completely absorbed, the object appears black.

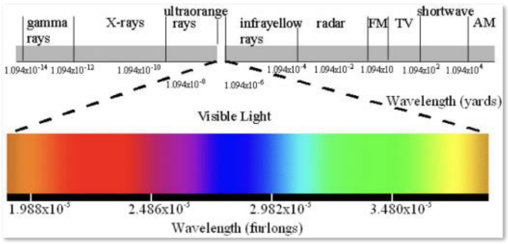

Figure 1: Electromagnetic waves ranging from radiowaves, microwave, infrared, ultraviolet (UV), xrays, and gamma rays, along with visible light having wavelength between 380 nm to 780 nm.[26]

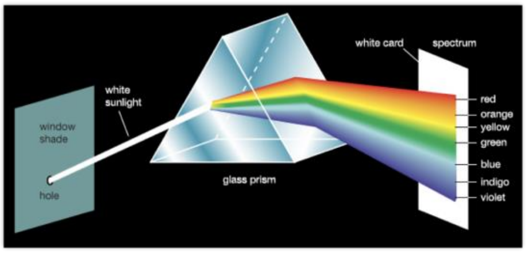

Figure 2: Sir Issac Newton with the help of a prism split white light pass through it into seven colors of varied wavelength.

3a.Color

Color, a unique property of light, is appreciated by the naked eye as a result of reflection of light from a surface. Objects have no color of their own. In fact they simply reflect a particular wavelength from the color spectrum. For instance a yellow object absorbs all of the wavelengths, except one wavelength which gets reflected and enters our eyes that we perceive as yellow. Light source, human eyes, and object onto which this visible spectrum of electromagnetic energy falls determines the sense of light and color.

3b.Description of Color

The most popular method for describing color is the Munsell system, described by Albert. H. Munsell in 1905.Hue, Chroma and Value are the three attributes of color in this system. Hue is defined as the particular variety of a color, the intensity or saturation of a hue is called Chroma and the relative darkness or lightness of a color is called Value **(Figure 3A).**

3c.Three Color Dimensions

Hue

The particular variety of a color is called hue **(Figure 3B)**. Hue differentiates color of one family from the another. It is that quality by which we distinguish one color family from another, as red from yellow, green from blue, or purple. It is a physiological and psychological interpretation of a sum of wavelengths. It is denoted by A (reddish brown), B (orange yellow), C (greenish-gray) or D (pinkish gray) on the commonly used shade guide of Vita Classic".

Value

Value measures light or dark shades or the brightness of a tooth color. It was classified by the Munsell method as a white-to-black gray scale **(Figure 3B)**. Bright items have less gray and more value, but low-value objects include more gray and appear darker. Increasing the surface reflectivity or reducing chroma are two common ways to improve dental crown brightness. Lowering the value means a lesser amount of light reflects from the lightened object and the extra light absorbs or is dispersed somewhere else.

Chroma

The saturation, intensity or power of a color is referred to as chroma. Chroma and value have a converse relation; if chroma is increased, the value is decreased or vice versa **(Figure 3B)**. In Munsell color system, where the radii of the different disc represent the chroma and the color at the outer edge of the disc is the pure color; as it goes toward the central axis, it becomes progressively less saturated. Chroma ranges from 2 to 10 for natural teeth.

3d.Types of color

Color is of two types, additive and subtractive. Additive Color are the ones obtained by emitted light.The primary additive colors are Red, Blue and Green and the secondary additive colors are Cyan, Yellow and Magenta. When additive primary colors are combined they produce white. Subtractive Colors are those associated with reflected light and are used in pigments for making paints, inks, fabrics etc. The primary

Journal of Chemical Health Risks
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JCHR (2024) 14(4), 169-178 | ISSN:2251-6727

subtractive colors are red, yellow, and blue and the secondary subtractive colors are green, violet and orange **(Figure 4)**. When subtractive primary colors are combined they produce black.[6]

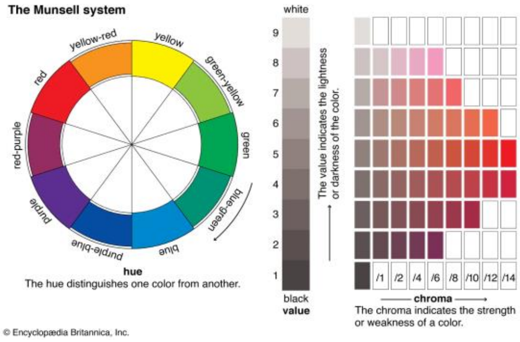
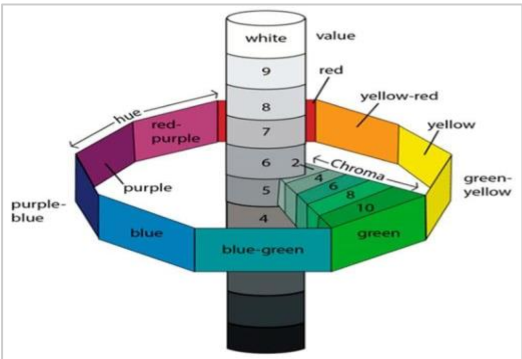


Figure 3A: Munsell color system showing color wheel, range of value and range of chroma.[26]



Munsell color system (adapted and re-drawn from ©1994 Encyclopedia Britannica, Inc., Chicago, IL, USA)., depicting the three dimensions of Hue, Value and Chroma.

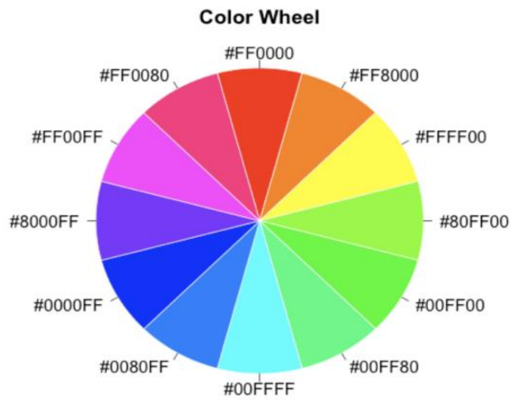


Figure 3C: Color wheel depicting compensatory colors on the Munsell Color system.[26]

4. Eye as the receptor

The initial process occurs in the retina of the eye. The retina contains photoreceptors that are sensitive to light. There are two types of photoreceptors, some shaped like rods and some like cones. These photoreceptors process light into nerve impulses and pass them along the cortex of the brain via the optic nerve, following which the perception of color takes place. 120 million rods, in the outer edges of the retina help eyes adjust when one enters a dark room. They are good for detecting motion and for seeing in low light-levels.[7] At low light levels, the rods of the human eye are more dominant than the cones and color perception is lost. There are 6 million cones in each eyeball which are sensitive to colour. There are three types of cone cells, each sensitive to the long, medium or short wavelength of light (red, blue and green color respectively).

5. **Color Blindness**

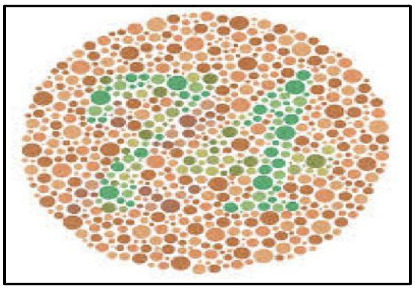
Color blindness, a genetic disease is the inability to distinguish the differences between particular colors.[7] This condition results from an absence of color-sensitive pigment in the cone cells of the retina **(Figure 5A)**. One in every twenty males suffer from some form of color blindness, but only one in several hundred females are color blind. Heredity, aging, certain medications, and retinal or optic nerve disease can also interfere with normal color vision.[8]

Different types of defects in color vision:(Figure 5B)

Achromatism: This is a sensitivity to hue entirely. The vision is without any ability to perceive chromatic color.

Dichromatism: Sensitivity to only two major hues, generally both red and green are not perceived.

Trichromatism: Sensitivity to all three hues with abnormality or deficiency in one of the three primary pigments or colors in the retinal cones.



A

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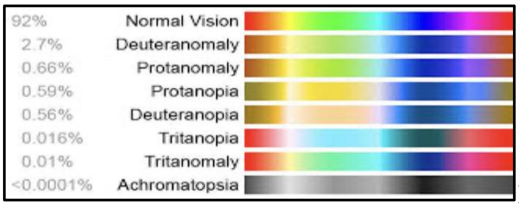
JCHR (2024) 14(4), 169-178 | ISSN:2251-6727



B

Figure 5A: Ishihara test and Farnsworth-Munsell 100 hue test for detecting color vision; **Figure 5B:** Range of vision including normal vision and impaired vision.

6.Factors affecting selection of shade

Quality of Light:

Energy distribution of a light has definite effects on the type of color being perceived. The clinician should use a source of light that contains full spectrum of rays without the dominance of any wavelength otherwise the specific color becomes dominant to the observer.

The color rendering index (CRI), on a scale of 1 to 100, indicates how well a particular light source renders color in comparison to a specific standard source.

Incandescent light source emits high concentration of yellow waves. It is not suitable for shade matching. It has low CRI. Fluorescent light emits high concentration of blue waves. It is not suitable for shade matching. It has CRI of 50-80.Third one is the natural daylight.[9] Northern daylight is considered ideal because it is closest to emitting the full spectrum of white light. It is used as the standard for any visible light source.It has CRI close to 100. Most dental offices are fitted with incandescent and fluorescent lights.

7. Optical Properties of Teeth

In addition to hue, value and chroma, translucency, opalescence, opacity, surface roughness, surface gloss and fluorescence, are the optical proprties exhibited by natural teeth. Depicting all the details present in a natural teeth results in life like appearance of restoration.

Human teeth can be categorized by the property of translucency, such as opaque and transparent. Usually, increasing the crown translucency consequently decreases its value because a smaller amount of light reflects towards the eye. The enamel translucency differs with texture, polish, wavelength and level of dryness. The translucency of the enamel is also a characteristic related to the refractive index of the enamel (RI = 1.62) and intercrystalline spatial composition. Demineralization alters the physiological reflectivity of the enamel, and the difference in RI between the healthy enamel and the demineralized area generates color alterations.[10]

7a.Fluorescence

Fluorescence which is the absorption of the entire light energy by a material and the spontaneous emission of light in a longer wavelength **(Figure 6)**. Higher concentration of organic material in the dentin of a human tooth, emits longer wavelength of energy and causes this phenomenon to occur. [10]

7b.Opalescence

Opalescence is the optical property of a material in which an object under reflected light appears different (blue) in color from the one with transmitted light (yellow). This distinctive impact is most frequently seen in enamel, which aids in mimicing liveliness and depth perception of natural tooth **(Figure 7)**. [11]

7c.Texture of Surface

This affects the esthetics of a tooth by determining the quantity and path of light that are reflected off the facial surface. Natural teeth may have various categorizations with lobes, stippling, striations and ridges.

7d. Surface Gloss

Surface gloss is also an optical property that gives a characteristic dimension to the real life effect of the restoration.

7e. Metamerism

When two colors appear to match under specific lighting conditions yet have differing shadow-like reflectances, known as metamers, the phenomenon is known as metamerism **(Figure 8)**.[12] By selecting a shade and authenticating it in general lighting conditions, such as fluorescent light and natural daylight, the problem of metamerism may be avoided or disregarded.

Figure 6: Florescence (optical phenomenon), exhibited by natural teeth under absorption of ultraviolet light source.[26]

Journal of Chemical Health Risks
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JCHR (2024) 14(4), 169-178 | ISSN:2251-6727

Figure 7: Phenomenon of opalescence, which appears blue under reflection of light and yellow/ orange under transmitted light.

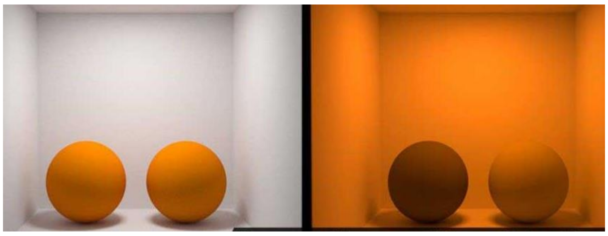

Figure 8: Phenomenon of metamerism of same objects under different light source.

8.Measurement of Colour

Investigators have measured the matching of shade as a subjective technique, which is dependent on some influences, such as source of light, object and viewer.

Shades can be measured using two techniques.[13,14,15]

A.Visual Technique

B. Instrumental Technique

Visual Technique

The Munsell system, which may be depicted in three dimensions of color, is a commonly used method for visually measuring tooth shade **(Figure 3A,3B,3C)**. It is economical and easily available in the market and the color of a tooth matches with a regular reference shade guide.The process is entirely dependant upon the observers power of visualisation. In some cases the visual approach for determining shade matching is inaccurate. Limitations include inadequate ambient lighting conditions, age, eye impairment and a strong reliance on individual abilities in shade matching and optical phenomenon like metamerism.[16]

9.Temperature of light

Another light source reference standard is color temperature, which is related to the color of a standard black body when heated. Color temperature is reported in degree Kelvin (K), or absolute (0°K = -273°C). Northern daylight has an average color temperature of around 6500°K, Time of day, cloud cover, humidity, and pollution are the variables that considerably affect the color temperature. Daylight is used as the standard against which other light sources are compared.

10.Guidelines for Shade Selection

i. Oral prophylaxis with removal of extrinsic stain and calculus needs to be done before shade selection.

ii. Bright shade lipstick or makeup should be avoided. Strong red lipstick next to the tooth will fatigue the red receptors while the blue and green receptors (complementary color on the color wheel chart) remain fresh and fully stimulated. This makes the tooth to appear bluegreen instead. Bright clothing should be draped with gray napkin. The operatory walls should be painted gray or background can have grey curtains. [17]

iii. Patient should be viewed at eye level and at arms length in alignment with the most sensitive part of the retina.

iv. Shade comparisons should be determined under different lighting conditions. Initial shade may be taken under a color corrected fluorescent light and then confirmed in natural daylight (taking patient to an operatory window).

v. Shade comparisons should be made at the beginning of a patient's visit. Teeth experiences increase in value when they are dry because of desiccation.

vi. Shade matching of natural teeth should be done with respect to both intra-oral and extra-oral tissue, followed by shade matching with respect to gingiva (soft tissue) and teeth (hard tissue) and finaly comparison between two hard tissues for example central and lateral incisor **(Figure 9A,9B)**. In case of shade selection from prepared tooth structure customised stump shade guides are used **(Figure 9C).** In natural teeth gingival colour, dentinal hue, enamel translucency can be derived by arbitrarily dividing the tooth into 6 small

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JCHR (2024) 14(4), 169-178 | ISSN:2251-6727

vii. Quick comparison (5 seconds), with shade tabs placed just under the lip and adjacent to the teeth to be matched. After 5 seconds of staring at a tooth or a shade guide, the eye accommodates and becomes biased resulting in hue sensitivity. If one stares at any color for longer than 5 seconds and then stares away at a white surface, or closes one's eyes, the image appears in the complementary hue (color opposite to each other in a color wheel). This phenomenon is known as hue sensitivity which affects shade selection **(Figure 3C)**.

viii. Looking at a gray walls or curtain between each shade evaluation relaxes the eye against hue sensitisation.

Figure 9A

Figure 9B&9C

Figure 9D

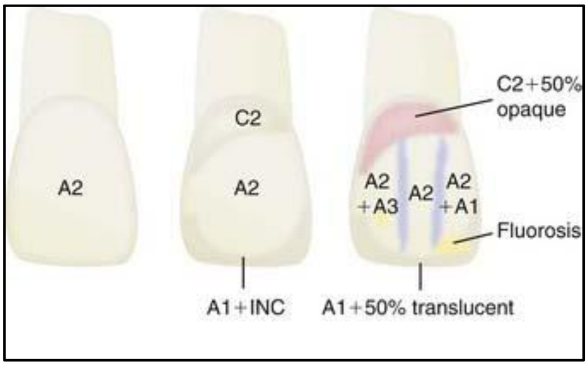

Figure 9E

Figure 9: Shade matching of natural teeth , A) with respect to both intra-oral and extra-oral tissue, B&C) with respect to gingiva (soft tissue) and teeth (hard tissue), D) comparison between two hard tissues (for example central and lateral incisor).E) Dividing the natural crown into 9 zones and segmental shade matching.

11a. Age

Shade-matching skills become unfavorable due to aging because the cornea and lens of the eye yellow with age, conveying a yellow-brown bias. This change starts at the age of 30 problems arises in distinguishing blue and purple colors. [18]

11b. Gender

Red and green cones may be more developed in females and this is proved by their affinity towards shades of red and green colors. Men were generally more tolerant towards achromatic colors than women. Therefore, women might be more color-conscious and their color tastes more flexible, diverse and accurate. [19]

12.Recommended Protocols for Clinical Shade Selection

12a.At first, the value is selected for the arrangement of the selection of shade followed by chroma, and finally hue.

12b.Condition of Teeth

Neighboring teeth must be free of surface stains and plaque along with other deposits. The tooth of interest must be moist with saliva because a lack of moisture will result in increased value. During the selection of shade, teeth must be distributed into three areas each time, such as gingival area (measurement of dentinal chroma),

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(4), 169-178 | ISSN:2251-6727

middle and incisal area (where enamel is more dense and differs in value).

12c.Distance of the Operator from the Tooth, Position of the Patient and Timing

A distance from the oral cavity of 2 to 6 feet is preferably considered for the matching of shade. The position of a patient on the dental chair should be at the level of the operator's eyes. Shade selection must be finalized by the operator in the morning preferably as fatigue of eye is minimal.

13.Types of shade guide

The most popular shade guides currently used for dental shade matching are: - Vita Classic (Vita Zahnfabrik, Bad Sackingen, Germany) - Vitapan 3D-Master (Vita Zahnfabrik, Bad Sackingen, Germany) - Chromascop (Ivoclar - Vivadent, Schaan, Liechtenstein) - Custom or specific chroma and value guides Vita Classic Shade Guide.[20]

13a.Vita Classic shade guide:

Tabs of similar hue are grouped into letter groups like:

A (hue of red-yellow) - A1, A2, A3, A3.5, A4, B (hue of yellow) - B1, B2, B3, B4 C (hue of gray) - C1, C2, C3, C4 D (hue of red-yellow-gray) - D2, D3, D4. Chroma is designated with numerical values 1, 2, 3 and 4. Every letter group has sub-divisions indexed with Arabic numbers, ranging from 1 to 4, which makes the overall number of tabs a total of 16. They are based on Munsell's guiding principles that distribute the color space into three dimensions: hue (name of the color), chroma (color density) and value (vitality of color).

Sequence for shade matching while using Vita Classic shade guide (Figure 10A)

Step 1: **Hue Selection**

Operator should select hue closest to that of natural tooth. Area of tooth highest in chroma is used for hue selection. [21]

Step 2: **Chroma Selection**

Once the Hue selection has been made, for example B. Chroma is selected from gradations within the B tabs - B1, B2, B3, and B4. Several comparisons should be made, avoiding retinal fatigue by giving eyes rest, between comparisons (looking at gray walls or curtains).

Step 3: For selection of value, use of a second, value oriented shade guide is recommended. Value oriented shade guide: B1, A1, B2, D2, A2, C1, C2, D4, A3, D3, B3, A3.5, B4, C3, A4, C4, Final value is selected by using a second shade guide whose samples are arranged with light shade tabs first and dark shade tabs last.

Squinting reduces the amount of light that reaches the retina. Therefore stimulation of the cones is reduced while rods become more sensitive to the increasingly achromatic conditions. The dentist should concentrate on which color disappears first - the tooth or the shade tab. The one the fades first has the lower value.

13b.Vitapan 3D-Master (Figure 10B)

Introduced in the early 1990s,the 3D-Master attempts a three dimensional analysis of tooth color. The 3D-Master differs from the classic shade guide in having, the tabs arranged systematically and logically, rather than the randomly placed tabs The tabs are grouped into five categories, sequentially numbered, with an increasing value (1, 2, 3, 4 and 5). All tabs within a value group have the same brightness. In a given value group, the chroma increases from top to bottom. All groups, with the exception of 1 and 5, are designated three letters, L, M and R, corresponding to varying hue. For example 2M2 corresponds to the second value group, the M hue subgroup and a 2-chroma level. For an intermediate tooth shade, a combination of two tabs is used for the final color prescription.

13c.Chromascop (Figure 10C)

The Chromascop uses numbers to distinguish hue, e.g., 100 (white), 200 (yellow), 300 (orange), 400 (grey) and 500 (brown). Chroma is indicated by another set of numbers, 10 are high value with low chroma, while 40 is low value with high chroma. A conversion chart is available to convert Chromascop shade tabs to the Vita Classic shades. Custom guides: If the tooth color fails to concur with any of the shade guide, and extremes of value and chroma are required, specific detailed chroma and value guides are available in customised form. Aged teeth of deep chroma, or youthful teeth with high values are such conditions.

13d.Demerits of Shade Guides

i. In shade guides, the colors may differ for each company. [22]

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(4), 169-178 | ISSN:2251-6727

ii. Guides are not able to direct the accurate manufacturing of porcelain restoration of that particular shade.

iii. The shades of a tooth in a shade guide fail to cover the capacity of color space that is normally unoccupied in natural teeth.

iv. A normal shade tab is prepared from synthetic resin having greater density than a crown.

Figure 10A. Vita Classical Shade Guide.[26]

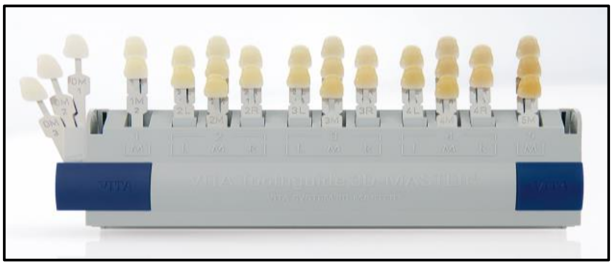

Figure 10 B. Vita 3D Master Shade Guide.

14.Instrumental Techniques in Tooth Shade Selection

Selection of shade is considered a subjective phenomenon as it is influenced by age, gender, eye fatigue, observer skill and surrounding light. Even though instrumental techniques in dental color matching are expensive they provide accurate results **(Figure 11A)**.The human eye, which can only distinguish 1% of these dental hues, electronic instruments can classify about 100,000 dental shades.

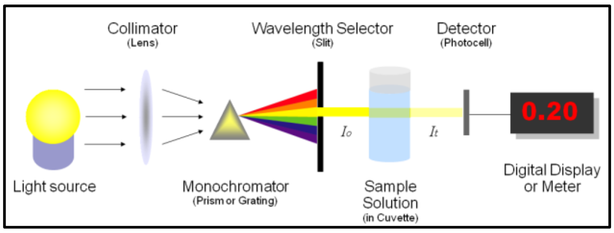

Figure 11A: Mechanism of conversion of light source to digital media (Instrumental technique). [26]

14a.Spectrophotometers (Figure 11B)

In dentistry, spectrophotometers are precise in general color matching. They quantify the extent of reflected light energy from an object at 1–25 nm intervals alongside the observable spectrum.[23]

A spectrophotometer varies from spectroradiometer as it mostly comprises a stable light source. These gadgets have been made using two different straightforward designs. The standard scanning apparatus has a single photodiode sensor that counts the amount of light at all wavelengths. The latest designed devices employ a diode arrangement with a specified element for every wavelength. This design supports the synchronized incorporation of all wavelengths simultaneously. Vita Easy Shade® V is an illustration of a spectrophotometer.

14b.Digital Cameras and Imaging Systems

Digital imaging systems are becoming progressively more widespread in measuring the shade of teeth. The quality of the camera and image-processing method affects its precision and accuracy. The digital cameras may be dependable instruments for determining the color of teeth and gingiva when applied in combination with the proper standardization procedures.[24]

Figure 11B: Portable spectrophotometer

15. Limitations of Digital Shade Guide

1.The color measurement accurateness is affected due to the loss of power supply.

2.For all systems, translucent recording is insufficient.

16.Laboratory communication

The key factor to successful fabrication of restoration is providing a detailed laboratory instruction through a laboratory instruction sheet.[25] This not only bridges the gap of communication, but also keeps record of the work for future reference **(Figure 12)**.

Journal of Chemical Health Risks
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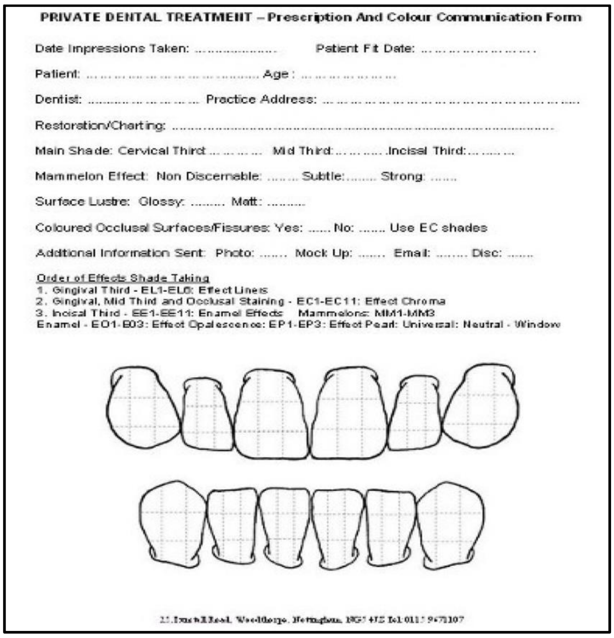
PRIVATE DENTAL TREATMENT – Prescription And Colour Communication Form

Date Impressions Taken: ………………… Patient Fit Date: ……………………

Patient: ……………………………… Age : ……………………

Dentist: ……………………… Practice Address: ………………………………………………

Restoration/Charting: ……………………………………………………………………

Main Shade: Cervical Third ………… Mid Third: ……… .Incisal Third: ………

Mammelon Effect: Non Discernable: ……. Subtle:…….. Strong: …….

Surface Lustre: Glossy: ……… Matt: ………

Coloured Occlusal Surfaces/Fissures: Yes: …… No: ……. Use EC shades

Additional Information Sent: Photo: ……. Mock Up: ……. Email: …….. Disc: …….

Order of Effects Shade Taking
1. Gingival Third - EL1-EL6: Effect Lines
2. Gingival, Mid Third and Occlusal Staining - EC1-EC11: Effect Chroma
3. Incisal Third - EE1-EE11: Enamel Effects Mammelons: MM1-MM3
Enamel - EO1-E03: Effect Opalescence: EP1-EP3: Effect Pearl: Universal: Neutral - Window

Figure 12: Color communication form for easy collaboration with laboratory technicians.

17.Conclusion

Understanding of the science of color and color perception from all aspects is beyond the scope of this review article. The prime factor of challange is depicting reality and depth in fabricating the restoration.Shade selection should be approached in a methodical and organized manner. This will enable the practitioner to determine the best choice and communicate it accurately to the laboratory.

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