THE RELATIONSHIP BETWEEN UPPER ANTERIOR TEETH COLOUR AND SKIN COLOUR IN BOTH GENDERS AMONG MALAYSIANS IN USM HEALTH CAMPUS POPULATION

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by

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OPERATIONAL DEFFINITIONS

Colour	Is a result of physical modification of light that is absorbed by the eye and illuminated by the brain (Billmeyer & Saltzman, 1966)
Mesnsell colour system	Describes colour in three dimensions: Hue, Value, and Chroma.
Hue	Is the colour of an object that differentiates one family of colour than another.
Value	Brightness, the amount of light returned from an object.
Chroma	The amount of dye that the colour contains, the strength of colour.
Commission International de I'Eclarirage (CIELab) System	Is the description of colour in numerical values. These values can locate an object in a three-dimensional (3D) colour space L*, a*, and b*. (Elamin, Abubakr, & Ibrahim. 2015).
L*	Lightness dimension, from 0 = black to 100 = white
a*	Green-red dimension, were negative figures (-) represent green colour, and positive figures (+) represent red colour
b*	Blue-yellow dimension, were negative figures (-) represent blue colour, and positive figures (+) represent yellow colour
Conventional tooth shade selection	Is a simple way using the operator eyes to choose the best match of tooth colour from tooth colour scale
Digital tooth shade selection	Is using electronic or digital equipment to choose tooth colour.
Edge loss	Is a gape in the edges of direct contact spectrophotometer window. As it leads to loss of light causing discrepancies in colour determination and lower value reading (Ten Bosch, Borsboom, van der Burgt, & Kortsmit, 1985; van der Burgt, 1985).
Colour difference (ΔE)	Is the colour difference between two colours.

LIST OF ABBREVIATIONS

CIELab	Commission International de I'Eclarirage System
ΔE	Colour difference
N	Number
SD	Standard Deviation
SDS	School of Dental Sciences
HUSM	Hospital Universiti Sains Malaysia
USM	Universiti Sains Malaysia

LIST OF APPENDICES

HUBUNGKAIT ANTARA WARNA GIGI ANTERIOR ATAS DAN KULIT KEPADA KEDUA-DUA JANTINA DALAM KALANGAN RAKYAT MALAYSIA DI KAMPUS KESIHATAN USM

ABSTRAK

Pemilihan warna adalah kaedah yang digunakan dalam pergigian untuk memilih warna gigi tiruan. Walau bagaimanapun, pemilihan warna tidak boleh dilakukan dalam sesetengah kes apabila gigi bersebelahan hilang, berubah warna atau tidak sihat. Oleh itu, pemilihan warna gigi mengikut ciri muka telah dicadangkan oleh kajian lepas. Salah satu ciri ini ialah warna kulit. Matlamat kajian ini adalah untuk mencari dan memodelkan hubungan antara warna gigi dan warna kulit dengan cara yang boleh digunakan dalam pergigian.

Persampelan mudah telah dilakukan untuk memilih 150 kakitangan dan pelajar dalam kalangan rakyat Malaysia di Hospital Universiti Sains Malaysia, Kampus Kesihatan, dengan taburan jantina sama rata (75 lelaki/75 perempuan) untuk menyertai kajian ini. Fotografi digital digunakan untuk mengukur warna kulit dan warna gigi kacip tengah dan sisi maksila dengan mengambil gambar muka dan gigi peserta dalam tetapan piawai. Foto telah ditentukur dalam Adobe Lightroom, dan kemudian pengukuran warna dilakukan dalam Adobe Photoshop. Spektrofotometer Vita Easyshade juga digunakan untuk mengukur warna gigi kacip maksila. Ciri warna telah diterangkan dalam sistem CIELab. Microsoft Excel digunakan untuk membangunkan prototaip Carta Warna Kulit, dan Carta Warna Kulit-Gigi dengan mempertimbangkan perbezaan warna ΔE sebagai faktor mengawal klasifikasi warna.

Keputusan ujian-t menunjukkan terdapat perbezaan yang signifikan dalam bacaan warna antara Spektrofotometer Vita Easyshade dan fotografi digital dalam semua ujian.

Ujian-t juga menunjukkan bahawa spektrofotometer tidak menunjukkan sebarang perbezaan yang ketara antara warna gigi lelaki dan perempuan. Sebaliknya, fotografi digital menunjukkan bahawa perempuan mempunyai gigi yang lebih putih berbanding lelaki pada gigi kacip tengah ($p < 0.05$) dan pada gigi kacip sisi ($p = 0.05$) pada tahap signifikan 0.05.

Tiga persamaan terhasil daripada analisis regresi berbilang yang menggambarkan hubungan langsung dalam bacaan kamera digital antara warna gigi (pembolehubah bersandar), dan warna kulit, jenis gigi dan jantina (pembolehubah bebas) untuk meramalkan warna gigi.

Dua prototaip carta warna telah dibangunkan dalam kajian ini, carta warna Kulit-Gigi yang dipacu daripada Carta Warna Kulit. Kedua-dua carta ini boleh digunakan sebagai alat panduan di klinik untuk memilih warna gigi dengan memadankannya dengan warna kulit.

Dengan mempertimbangkan keputusan ini, warna gigi boleh diramalkan dengan menggunakan persamaan kajian ini, atau dengan menggunakan carta warna gigi-kulit. Kajian lanjut perlu dilakukan untuk menyiasat variasi carta warna kulit-gigi dalam sampel yang lebih besar dan pelbagai.

THE RELATIONSHUP BETWEEN UPPER ANTERIOR TEETH COLOUR AND SKIN COLOUR IN BOTH GENDERS AMONG MALAYSIANS IN USM HEALTH CAMPUS POPULATION

ABSTRACT

Shade matching is the method used in dentistry to select artificial teeth colour. However, shade matching is not possible in some cases where the adjacent tooth is missing, discoloured, or unhealthy. Therefore, tooth colour shade selection according to adjacent facial features were suggested by previous studies to be used. One of these features was skin colour. The aim of this study was to find and model the relationship between tooth colour and skin colour in a way that can be used in dentistry.

A convenience sampling was done to select 150 Malaysian staff and students of the Hospital Universiti Sains Malaysia, Health Campus, with equal sex distribution (75 males/ 75 females) to participate in this study. Digital photography was used to measure skin colour and maxillary central and lateral incisors' colour by taking photos of participants' faces and teeth in standardized settings. Photos were calibrated in Adobe Lightroom, and then colour measurement was done in Adobe Photoshop. Vita Easyshade spectrophotometer was also used to measure maxillary incisors' colour. The form of colours was described in CIELab system. Microsoft Excel was used to develop the prototypes of Skin Shades Colour Chart, and Skin-Tooth Colour Chart by considering the colour differences ΔE as the controlling factor of colour classifications.

The results of the t-test showed that there were significant differences in colour readings between Vita Easyshade Spectrophotometer and digital photography in all tests.

The t-test also showed that spectrophotometer did not show any significant differences between males and females tooth colour. On the other hand, digital photography showed that females had lighter teeth than males in central incisors ($p < 0.05$) and in lateral incisors ($p = 0.05$) at significant level of 0.05.

Three equations resulted from multiple regression analysis that described the direct relationship in digital camera's readings between tooth colour (dependent variable), and skin colour, tooth type, and gender (independent variables) to predict tooth colour.

Two prototypes of colour charts were developed in this study, Skin-Tooth colour chart that was driven from the Skin Shades Colour Chart. These two charts may be used as a guiding tool in clinics for selecting tooth colour by matching the charts with skin colour.

By considering these results, tooth colour can be predicted by using the equations of this study, or by using the skin-tooth colour chart. Further studies should be done to investigate the skin-tooth colour chart variations in larger and diverse samples.

CHAPTER 1

INTRODUCTION

1.1 General Introduction

The demands for aesthetic restorations have increased lately as they seem to define one's character (Samorodnitzky-Naveh *et al*., 2007). So far, determining the colour shade for patients' anterior artificial teeth is considered a challenge for dentists as it is a subjective matter. It can even be more difficult if patients have carious, discoloured, malformed teeth, or if they were edentulous.

Many companies contented to create the best and easiest tooth shade guides to make tooth colour shade matching procedure easier and more accurate. However, these companies described the colour shade as a single generic colour that can be matched and compared with another adjacent tooth in the patient’s mouth; but cannot predict a perfect match if there were no teeth to compare with. Therefore, in selecting the shade of patient’s teeth, shade guides are useful as comparison with healthy, non-stained anterior teeth, and for posterior teeth.

1.2 Background of the Study

1.2.1 Surrounding Environment (Skin)

Several studies have been done to find a perfect way to predict tooth shades for cases where it is not suitable to use the standard tooth shade guides. "Preparing a colour shade map, indicating the various colour shades of tooth and its surrounding environment is more likely to help achieve a better result than by merely describing the colour shade as a single generic colour (Freedman, 2012)". Jahangiri *et al.* said “There is limited scientific information on the relationship between tooth shade and skin colour. This lack of knowledge may impact the ability of the prosthodontist to select artificial teeth that complement the facial complexion of the patient" (Jahangiri *et al*., 2002).

Therefore, much research was done to find a way to eliminate the inaccurate tooth colour shade selections to make it easier and more natural. Some researchers suggested that tooth shades can be influenced by skin colour, eye colour, hair colour, age, and gender. Boucher *et al.* reported that the hair colour is an unreliable for tooth shade selection guide because hair colour changes more rapidly that the teeth and people also change the colour of their hair. He also did conclude that the usage of the colour of the eye as a guide is questionable because eyes are not close to the teeth and the pupils are very small when compared to the face (Boucher *et al.*, 1990). On the other hand, many researches were done to study the relationship between skin tones and tooth colour (Al-Nsour *et al*., 2018; Jahangiri *et al*., 2002; Sabherwal *et al*., 2009; Sharma *et al*., 2010; Susanty *et al*., 2018; Vadavadagi *et al*., 2016; Veeraganta *et al*., 2015). A study found that "the colour of the facial skin serves as the basic guide to tooth shade. The face is the frame into which the teeth will fit in. Therefore, the colour of the teeth should harmonize with the colour of the skin of the face" (Azad *et al*., 2007).

1.2.2 Methods of colour measurement (Visual shade matching and digital shade matching)

Different materials and methods used in previous studies lead to different results. Some researchers used the conventional visual tooth shade scale in their study. It was reported that visual tooth shade selection and the tooth colour are influenced by many factors such as age, gender, smoking, nutrition, xerostomia, dental experience, colour blindness, eye fatigue and lightening condition (Dewangan & Dewangan, 2018; Dummett *et al*., 1980; Karaman *et al*., 2019; Veeraganta *et al*., 2015). These factors can lead to different results (Dewangan & Dewangan, 2018; Dozić *et al*., 2007; Dummett *et al.*, 1980). Moreover, the clinical skills of a dentist and the shade guide system used can also lead to different results (Dewangan & Dewangan, 2018). Therefore, digital devices, such as spectrophotometers ensure accurate, reliable, and objective measurement of tooth colour compared to subjective visual methods (Bahannan, 2014; Chen *et al*., 2012; Karaman *et al*., 2019; Pimental & Tiossi, 2014).

1.3 Problem Statement

In patients who lost some of the teeth, it is easy to select the colour of the tooth for prosthesis as the dentist can refer to the shade of remaining teeth. However, in patients who have lost all teeth, then the patient skin colour is usually used as guide. However, until now there is no specific skin guide or standard protocol that can help dentists to match skin colour to tooth colour objectively. Most of the research done used a subjective visual assessment and classification of skin tones such as dark, fair, and medium. It is challenging for the dentist to make an objective skin and tooth shade selection using subjective visual assessment due to factors explained earlier.

1.4 Justification of the Study

Therefore, this study was conducted to create a guide or a standard protocol, so that tooth colour selection in relation to skin tones can be done objectively using an accurate and reliable digital skin and tooth shade guides. This would help dentists clinically to provide potential guideline for tooth colour selection from patient's skin tone without confusion. Moreover, the information from this study would provide the dental technician with as much objective information as possible on colour characteristics of the dental prosthesis to be constructed.

1.5 Research objectives

1.5.1 General Objective

To assess the relationship between skin colour readings and tooth colour readings in Malaysian males and females in the Health Campus of Hospital Universiti Sains Malaysia (USM).

1.5.2 Specific Objectives

1. To determine the skin colour tones among males and females of the Malaysian population in the Health Campus, Hospital Universiti Sains Malaysia.
2. To determine and compare tooth colour readings using VITA Easyshade spectrophotometer and digital camera photography among Malaysian males and females in the Health Campus, Hospital Universiti Sains Malaysia.
3. To model the relationship between tooth colour readings and skin colour readings in different genders among Malaysian in the Health Campus, Hospital Universiti Sains Malaysia.
4. To develop a prototype of Skin Colour Shades Chart among Malaysian in the Health Campus, Hospital Universiti Sains Malaysia.
5. To develop a prototype of Skin-Tooth Colour Shades Chart among Malaysian in the Health Campus, Hospital Universiti Sains Malaysia.

1.6 Research Questions

1. It is possible to determine the skin colour tones among males and females of the Malaysian population in the Health Campus, Hospital Universiti Sains Malaysia.
2. There are significant differences between VITA Easyshade spectrophotometer and digital camera photography L, a, b tooth colour readings of central and lateral incisors in different genders among Malaysians attending the Health Campus, Hospital Universiti Sains Malaysia.
3. There are significant relationships between tooth colour readings and skin colour readings in different genders among Malaysians attending the Health Campus, Hospital Universiti Sains Malaysia.
4. Is it possible to develop a prototype of Skin Colour Shades Chart among Malaysians in the Health Campus, Hospital Universiti Sains Malaysia.
5. Is it possible to develop a prototype of Skin-Tooth Colour Shades Chart among Malaysians in the Health Campus, Hospital Universiti Sains Malaysia.

1.7 Research Hypotheses

1. It is possible to determine the skin colour tones among males and females of the Malaysian population in the Health Campus, Hospital Universiti Sains Malaysia.
2. There are significant differences between VITA Easyshade spectrophotometer and digital camera photography L, a, b tooth colour readings of central and lateral incisors in different genders among Malaysians attending the Health Campus, Hospital Universiti Sains Malaysia.

3. There are significant relationships between tooth colour readings and skin colour readings in different genders among Malaysians attending the Health Campus, Hospital Universiti Sains Malaysia.
4. It is possible to develop a prototype of Skin Colour Shades Chart among Malaysians in the Health Campus, Hospital Universiti Sains Malaysia.
5. It is possible to develop a prototype of Skin-Tooth Colour Shades Chart among Malaysians in the Health Campus, Hospital Universiti Sains Malaysia.

CHAPTER 2

LITERATURE REVIEW

2.1 Colour

Colour is a result of physical modification of light that is absorbed by the eye and illuminated by the brain (Billmeyer & Saltzman, 1966). The human eye can see colours due to light, in wave light between 400 to 800 nm along the electromagnetic spectrum (guiding *et al.*, 2006), as shown in Figure 2.1.

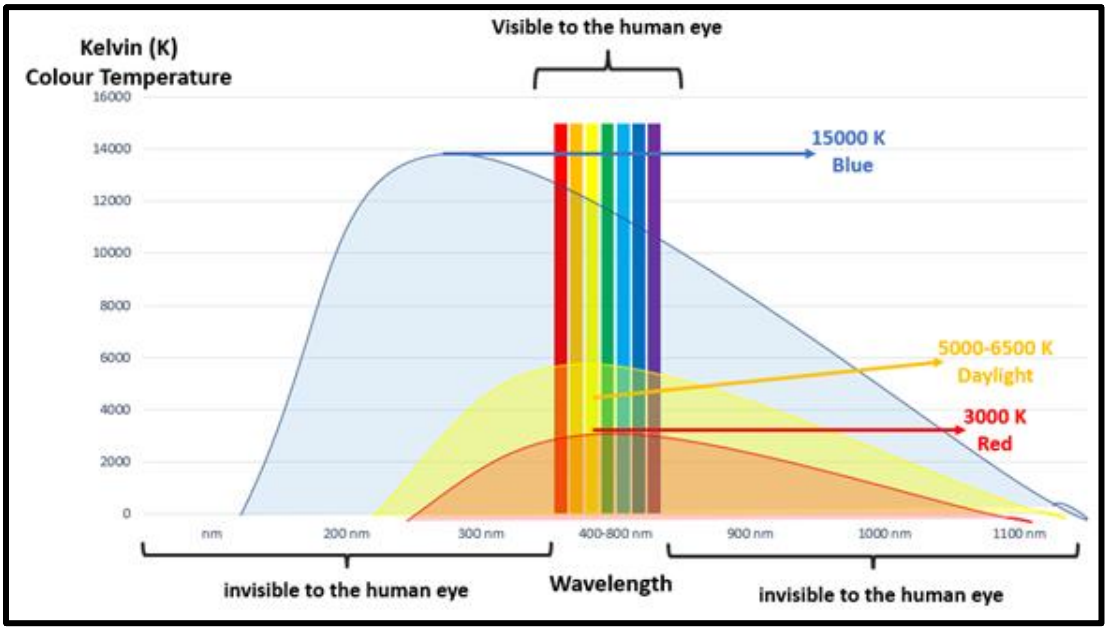

Figure 2.1 Wavelength and colour temperature of light

Sikri stated that the reflected components of incident white light determine the colour of an object. Therefore, the quality of light plays an important role in detecting colours (Sikri, 2010). Sikri also stated that the first circular colour diagram was designed by Sir Isaac Newton in 1666, and the most common vision of the colour wheel is the wheel of 12 colours (Figure 2.2).

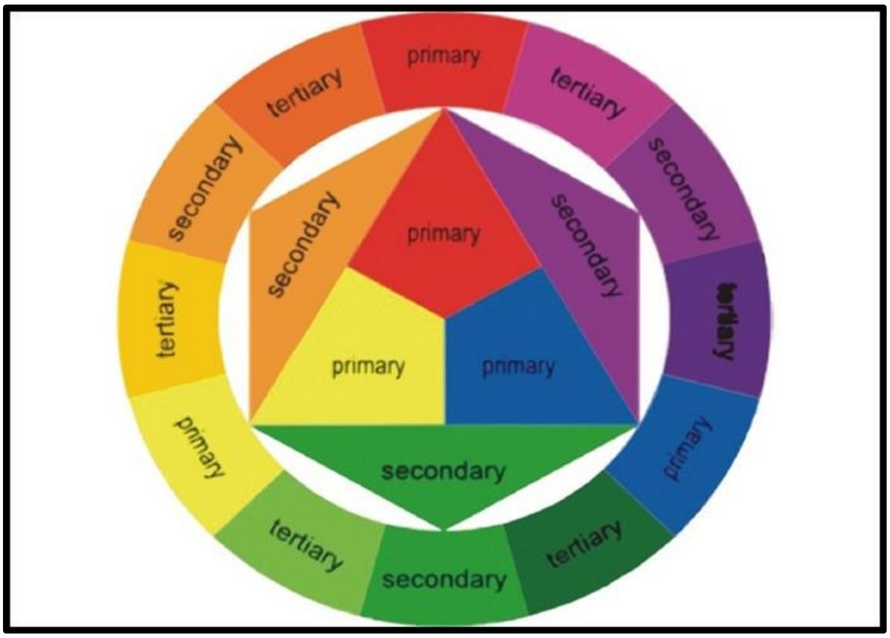

Figure 2.2 Colour Wheel; Sikri, 2010

This wheel has primary colours, red, yellow, and blue, and secondary colours, green, orange, and purple. Secondary colours were created by mixing two primary colours. By mixing a primary colour with a secondary colour, six tertiary colours were created (Sikri, 2010).

Albert Munsell described colour as a three-dimensional phenomenon, hue, value, and chroma (Fondriest, 2003). Hue describes the colour family, yellow, green, blue and other colours. Value describes the brightness of the colour, and chroma describes the strength of hue (Fondriest, 2003; Fuletra *et al*., 2014; Sikri, 2010).

2.1.1 Colour Description

There are two systems used to describe colour, the first system is the Munsell colour system that describes colour in three attributes: Hue, Value, and Chroma. Hue is the colour of an object that distinguishes one family of colours from another. Hue is represented by A, B, C, or D in dental terms on Vita Classic Shade Guide. Value is the amount of light returned from an object (brightness). The maximum value is white, and the minimum value is black. The more grayish an object the less bright it becomes. Chroma is the amount of dye that the colour contains. It is also known as the strength of the hue. Chroma and value are inversely related, meaning that when chroma increased, the value is decreased (Fuletra *et al*., 2014).

The second system is the Commission International de I'Eclarirage (CIELab) system. The CIELab describes colour in numerical values as the product of blending in three coordinates: L*, a*, and b*. These values can locate an object in a three-dimensional (3D) colour space (Elamin *et al.,* 2015).

2.1.2 Colour in Dentistry

G. V. Black was the first to highlight the importance of value in the shade determination process. He stated in a work published in 1908 that the best esthetic result was obtained when the proper colour (hue) and translucence (value) were determined (Black, 1908; Esan *et al*., 2006). However, this view increased the esthetic results of restorations when considered during fabrication, but it did not help in how to choose tooth colour shade in anterior teeth rehabilitation cases.

One of the companies that produces tooth shade guides is VITA Zahnfabrik which was founded in 1924. VITA Zahnfabrik developed Vitapan Classical shade guide that has 16 different shades (A1-A4 reddish brownish, B1-B4 reddish yellowish, C1-C4 greyish shades, D2-D4 reddish grey). VITA Zahnfabrik has also developed VITA 3D-Master shade guide that has 26 natural and systemically arranged tooth shades in addition to three shades for tooth whitening. O'Brien *et al*. reported that Vitapan 3D Master Guide covered approximates 25% of the colour range of human teeth (O'Brien *et al*., 1997). It was also reported that Vitapan Classical Shade Guide with 16 shades cover only 6% of human teeth colour, and when the two shade guides are combined, they could cover as high as 52% (Paravina *et al*., 2002). Recently, VITA Zahnfabrik created a new digital device for tooth colour shade determination, VITA Easyshade V Digital Spectrophotometer that can mix two VITA SYSTEM 3D-MASTER shades. This device increased the range of natural tooth colour shades. In 2012, Freedman suggested that tooth shade selections presume predictable shade determination. Preparing a colour shade map, indicating the various colour shades of a tooth and its surrounding environment is more likely to help achieve better results than by merely describing the colour shade as a single generic colour. All tooth shade systems describe tooth colour shade as a single generic colour and that is why the outcomes are not always satisfying (Freedman, 2012).

A study found that tooth shades could be influenced by skin colour, eye colour, hair colour, age, gender. However, none of the results were definitive (Boucher *et al.*, 1990).

A study was conducted to find the relationship between tooth colour and some variables; skin colour, hair colour, eye colour, and gender. It was reported that the hair colour is an unreliable, and eye colour is questionable to use it as guide for tooth shade selection because hair colour changes more rapidly than the teeth and people also change the colour of their hair. The size of the pupils of eyes in comparison to the face is considered small and located far from the teeth. On the other hand, there is a strong relation between skin colour, and gender and tooth colour (Boucher *et al*., 1990).

2.2 Tooth Colour Shade Selection and Measurement

There are two methods used in tooth shade selection: conventional (visual), and digital. Most dentists were thought to use conventional method to select colour by using naked eye. They used a tooth shade scale to match the colour of a patient natural tooth with the colour of the prosthetic tooth. However, this procedure is applicable only if the patient has healthy and non-stained dentition.

It was found that the human eye perception of colours can be affected by intake of some materials such as caffeine which darkens warm colors (yellow, orange, red) and lightens cold colors (purple, green, blue) (Vadher *et al*., 2014). Vadher *et al*. also reviewed the basics of colour in dentistry and explained the proper environment for colour reading. According to the authors, dental-unit lights that were used for colour readings were incandescent and emit light high in red-yellow spectrum (long wavelength) and low at the blue end. These lights make the enamel looks more translucent with a high chroma and lower value than it has and show more dentine. Therefore, light source with colour temperatures of between 5000° and 6500 °K are suggested during shade measurement. The authors also recommended Shade Light ™ KERR and Rite-Lite ADDENT lamp that offer D65 and D55 light respectively for ideal observation light (Vadher *et al*., 2014). On the other hand, another study stated that visual determination of shade selection to be unreliable and inconsistent due to many factors that could lead to incorrect readings of colour such as fatigue, aging, emotions (Sikri, 2010). This was supported by another study which stated colour matching in dentistry is a subjective process because it depends on light, tooth, and observer (Takatsui *et al*., 2012).

The other method used for tooth shade selection is digital method. Examples of this are spectrophotometers, colorimeters, digital cameras, and RGB devices (Bhat *et al*., 2011). Digital methods are more reliable and provide a more standardized measurement of colour compared with conventional tooth colour measurement methods (Bahannan, 2014; Chen *et al*., 2012; Pimental & Tiossi, 2014; Tuncdemir *et al*., 2012).

Many companies contended to create the best and easier tooth shade guides such as VITA Zahnfabrik Shade Guides, Chairside Shade Guide, Bioform Shade Guides, Trublend SLM Shade Guide, and OLYMPUS Crystaleye Spectrophotometer. Therefore, studies have been done to compare between different manual and digital shade guides, as will be discussed later. Moreover, there are some factors that these studies concentrated on, such as reliability and accuracy, factors affecting colour matching, and edge loss as will be discussed later.

2.2.1 Digital Tooth colour Measurement

2.2.1(a) Spectrophotometer

Spectrophotometer was introduced in dentistry to overcome incorrect colour readings and uncontrolled factors that affect colour readings. However, with all the benefits that came with spectrophotometers, there is a small gap in some designs of the edge of the spectrophotometer. Light that enters the tooth from spectrophotometer with small window and operates via direct contact with teeth may have considerable fraction of light reentering the tooth for example in VITA EasyShade spectrophotometer which causes discrepancies in colour determination and a lower value reading. This is because light emerges at tooth surface outside of the window of measurement, which was reported as edge loss (Barnes *et al*., 1990; Bolt *et al.,* 1994). It was reported also that the edge-loss effect was avoided in their study as they used a noncontact type of dental spectrophotometer with 45/08 geometry (Ishikawa-Nagai *et al*., 2009).

Figure 2.3 VITA Easyshade (Small window with direct contact), CrystelEye (Large window with no direct contact)

2.2.1(b) Digital Photography

Digital photography is one of the methods to measure tooth colour. It has been found that digital imaging systems are compatible to spectrophotometry in colour measurement if it was done properly. Digital imaging can provide additional information and measuring appearance attributes beyond intrinsic colour compared to spectrophotometry (Joiner & Luo, 2017). Digital photography can be used in colour measurement, legal documentation, publication, communication with patients and technicians (Casaglia *et al*., 2015). It can also be used as reference for dentists to evaluate, measure dimensions, and draw a new smile such as in Digital Smile Design (DSD) and 3Shape Smile Design.

Photo format in digital photography is also important as RAW photo format contains more information of the images, with its privacy protected including copyrights signature (Iyer, 2019).

A study was conducted to measure tooth colour in different tooth segment. In that study digital camera was used as a tool to measure tooth colour. An Olympus camera (CAMEDIA) was used with a ring flashlight and two lenses (F/1.8 to F/2.6 lens and a 55-macro conversion lens). A special positioning unit was also used. The colour analysis was done using a special software and the camera settings are shown in Table 2.1 (Dozic *et al*., 2004).

Another study was conducted to evaluate a developed software to measure tooth colour using digital photography. A Nikon D600 camera with Nikon AF-S VR 105mm f/2.8 IF-ED lens was used. Twin flash was also used for illumination and VITA EasyShade spectrophotometer was used as the reference of colour. The camera settings are shown in Table 2.1. Photo calibration was done using a shade tab that was photographed next to the targeted tooth. That tab was measured using spectrophotometer and the L*a*b* readings were recorded. The photos were then calibrated according to the L*a*b* readings of the spectrophotometer. The study showed strong significant correlation between the program used in measuring tooth colour and the VITA 3D Master shade guide ($p < 0.001$) (Culic *et al*., 2015).

These two studies used digital photography to measure tooth colour. They also used specific settings such as using illumination, position, camera settings, and calibrating photos.

2.2.1(c) Intraoral Camera and Colorimeter

One of the intraoral scanners used to scan and measure tooth colour is TRIOS 3 from 3Shape. A study used TRIOS 3 to measure its accuracy in compared to SpectroShade spectrophotometer. It was found that TRIOS 3 accuracy was higher with VITA 3D Master with 53.3%, than VITA classical shade guide with 27.5% when the

SpectroShade was used as the reference. The results also showed that the repeatability for SpectroShade spectrophotometer (92% VITA Master shade guide, 93.5% VITA Classical) was higher than TRIOS 3 (90.33% VITA Master shade guide, 87.17% VITA Classical) (Rutkunas *et al.*, 2020).

Another study also used TRIOS 3 from 3Shape with a spectrophotometer to compare the capability of colour measurement in different illumination conditions. It was found that different lighting conditions affect colour measurement with these devices as there was a significant difference between different illumination and colour (Revilla-Leon *et al.*, 2021).

Colorimeter is one of the methods that are used to measure tooth colour. A previous study used colorimeter in their study to measure the repeatability of the device. Minolta CR-321 colorimeter was used to measure the colour of the center of maxillary left central incisor. The device measuring head was reformed to be able to use it to measure tooth colour. The results showed that there was an accepted precision for intraoral measurement of longitudinal changes of tooth colour (Douglas, 1997).

2.2.2 Comparison between Digital and Conventional Tooth Colour Measurement

A previous study was conducted to evaluate the performance of three tooth colour detection devices compared to human eye. The devices used were SpectroShade MHT Optic Research AG software, Shade Vision from X-Rite software, and Digital Shade guide DSG4 software. Eye colour measurement was done using VITA Classical shade guide. The agreement between the devices and the human eye were diminutive (27.8% for DSG, 29.1% for SpectroShade, and 37.1% for Shade Vision). These computer's aided colour measurement methods do not reflect human perception if they were done without human visual control (Hugo *et al.*, 2005).

Liberato *et al*. in 2019 also found that digital methods were more reliable than conventional methods. The strongest reliability was shown for TRIOS 3Shape intra oral scanner followed by VITA Easyshade spectrophotometer, and finally VITA Classical shade scale with light correcting (Liberato *et al*., 2019).

Another study evaluated the efficiency of visual tooth colour selection in different lighting condition and different examiner experience in compared with instrumental methods. Two digital devices which included VITA Easyshade Compact spectrophotometer, and TRIOS 3 3Shape intraoral camera were used. The VITA 3D Master shade guide was used for visual shade matching. LED lights with colour temperature of 4000K and 6500K were also used. The study showed that visual colour measurement was not affected by examiner experience, and the light conditions did not affect colour measurement in both conventional and digital methods (Yilmaz *et al*., 2019).

Most of the studies that were included in the literature review in the present study used ΔE (Colour differences) to measure differences in colours between different readings or methods. ΔE was used to measure repeatability, reliability, measuring the reproducibility of colours, calculating systematic errors between means of ΔE, and compare between two colours.

Table 2.1 Studies that were reported on tooth colour measurement methods; conventional and/or digital

No.	Title and year	Aim	Type of measurement	Statistics used	Materials and method	Results
1	Precision of in vivo colorimetric assessments of teeth, (Douglas, 1997).	**Repeatability** of an intraoral positioning device	**Digital** (colourimeter)	• Intraclass correlation coefficients (**ICCs**) • Repeatability colour differences (Δ**E**)	**Materials:** Minolta CR-321 (Minolta Corp., Ramsey, N.J. **Measuring sight:** Canter of maxillary left central incisor. **Method:** The Minolta CR-321 measuring head was replaced by a Type V stone model fabrication after an impression made for the colourimeter.	- High ICCs were found for intraexaminer and interexaminer repeatability. - Repeatability colour differences for intraexaminer Δ**E=** 0.34 assessments, whereas Δ**E=** 0.13, and 0.61 for interexaminer for the two examiner pairs. - The colourimeter with a custom measuring head had acceptable precision for intraoral measurement of longitudinal changes in tooth colour.

2	Relation in colour of three regions of vital human incisors, (Dozic *et al*., 2004).	To determine **colour relation between** cervical, middle, and incisal **tooth segments**, and **to study** the possibility to get **reproducible** L*a*b*	**Digital** (Photography)	• For reproducibility: Mean and Standard deviation SD were calculated • Visual perceptibility of colour differences was calculated by finding the Mean **ΔE.** • Repeated measures were compared for Mean L*a*b* using ANOVA. • To find the quantitative relationship in colour between the three tooth segments, a comparison was made using Pearson correlation coefficients. • The relationship between L*a*b* readings and tooth segments were done using linear regression analysis.	**Materials:** • Camera: CAMEDIA C-2040ZOOM, Olympus, Tokyo, Japan) • Ring flash (Minolta 80 PX Macro Flashgun, Minolta, Osaka, Japan) • Software • Two lenses: F/1.8 to F/2.6 lens and macro-conversion lens (Ø 55 mm), F/40 (Olympus) • Positioning unit **Measuring sight:** Maxillary right central incisors. **Method:** Camera settings: - Resolution: 1024 x 768 pixels SHQ (high quality). - Colour depths: 24 bits (RGB scale). - Images were recorded in Manual mode chosen from the A/S/M still shooting mode. - Daylight white balance - Digital (ESP) metering - Manual focus (80 cm) - ISO 100 - Aperture F/7.00 - Shutter speed: 1/800	- The study showed a possibility of predicting tooth colour for a tooth segment from knowing the tooth colour of another segment. This can help in tooth colour mapping by knowing the colour of one part of the tooth. - There was a significant linear correlation between the three tooth segments for L*a*b* readings.

		readings for tooth segments **using digital camera.**			- External flash mode. - Standardized head-camera setup - A special positioning unit was used in this study.	
3	Comparison of in vivo visual and computer-aided tooth shade determination, (Hugo *et al*., 2005)	To **evaluate** the **performance** of three tooth shade colour detection devices	**Digital** (Three computer-aided devices) vs. **Conventional** (eyes)	• Agreement of individual methods with others • Agreement of all methods in the group • Agreement of the methods with the majority opinion • Agreement rates of all methods combinations	**Materials:** • SpectroShade MHT Optic Research AG, Software V.2.20D • ShadeVision X-Rite Co., Software V. 1.20 • Digital Shade Guide DSG4 Software V. 1.7 • Vita Classical shades **Measuring sight:** Maxillary central and lateral incisors and canine (six teeth) **Method:** • The measurements of the devices were compared with the three-observer perception. • Six groups of comparison of agreement were made (MHT-majority, X-Rite-majority, Reith-majority,	- Agreement between humans was 52.9% - Agreement between humans and SpectroShade was 29.1%. - Agreement between humans and ShadeVision was 37.1%. - Agreement between humans and DSG4 was 27.8%. - Computer-aided colour shade selection for natural teeth do not reflect human perception if it was not done with human visual control.

					student-majority, techn.1-majority, techn.2-majority)	
4	A comparison Between a New Visual Method of Colour Matching by Intraoral Camera and Conventional Visual and Spectrophotometric Methods, (Lasserre *et al.*, 2011).	To evaluate Sopro Shade concept of Sopro 717 intraoral camera by comparing it with VITA EasyShade spectrophotometer and VITA 3D Master.	**Digital**	• Kendall's tau-b rank correlation coefficient. (SPSS). • Two-tailed T-Tests for paired samples. (Excel).	**Materials:** • Sopro 717 intraoral camera • Vita 3D Master • True Shade lamp • VITA EasyShade spectrophotometer **Measuring sight:** Middle 3rd of Maxillary right central incisor and canine **Method:** • Colour evaluation was done twice in two days by three observers individually, using three methods. • All data recorded according to VITA 3D Master shade guide • Artificial light was used without natural daylight. • Environmental light intensity was 700 lux, and environmental colour temperature was 3750 K. • 1st colour selection was done under True Shade lamp to choose colour match using eye.	- In all three methods, inter-examiner reliability was higher for the canines than for the centrals. - Intra-examiner agreement was significant (p<0.5) between visual (True shade lamp + Vita 3d Master) and assisted visual method (Sopro 717 intraoral camera). - Kendall's tau-b correlation coefficient between the two visual methods and the spectrophotometer were low. - The agreement between the two visual methods was significant for canines and central incisors.

					• 2nd colour selection was done using Sopro 717 intraoral camera that take photos for participants' teeth. Then, these photos were viewed on computer screen and were compared with VITA 3D Master shade guide. • 3rd colour selection was done using VITA EasyShade spectrophotometer.	
5	Clinical Evaluation of a Dental Colour Analysis System: The Crystaleye Spectrophotometer, (Odaira, Itoh, &	To test the clinical performance of a dental colour analysis system called Crystaleye spectrophotometer	**Digital**	• To measure the **reliability** of the three colour measurement devices, the **Scheffe's F-test** was used. • To measure the **accuracy** of **repeated** colour measurement**, colour differences (ΔE)** between colour reading no. 1 and no. 10 was calculated. • To measure the **effect of exterior lighting** on the colour measurement**, T-Test** was used to compare between **two**	**Materials:** • Crystaleye Spectrophotometer • CAS-ID 1 • MSC-2000 **Measuring sight:** Maxillary left central incisor. **Method:** • Tooth colour was measured using Crystaleye spectrophotometer, CAS-ID 1, and MSC-2000. • Colour measurement was preformed 10 times using Crystaleye spectrophotometer. • Colour measurement was preformed three times in light condition, and three	- There were no significant differences between the three colour measurement devices. - Colour differences for repeated colour measurement was ΔE=0.6 - Colour differences between light and dark moods was ΔE=0.9 - There were no significant differences between the measurements by different examiners. - The mean colour differences between target tooth and fabricated crown ΔE= 1.2 ± 0.4.

	Ishibashi, 2011)			**different conditions of lighting.** • To measure the **examiners' efficiency,** five examiners measured tooth colour three times. The differences between them were measured using **Scheffe's F-test.** • **Reproducibility** of tooth colour for Crystaleye spectrophotometer was measured by finding colour differences (**ΔE) between targeted tooth and the new fabricated crown.**	times in dark condition using Crystalyey spectrophotometer. • Colour measurement was done five times by three examiners using Crystaleye spectrophotometer. • After that, multiple statistical tests were performed. • For reproducibility of colour, a treatment case was done for a patient to restore a crown for maxillary central incisor. The colour measurement was done for a targeted tooth and for the restorative crown using Crystaleye spectrophotometer.	
6	Reliability of Shade Selection	To evaluate the reproducibility	Digital	• Measure of precision was done by finding the validity of MCDM from the mean colour difference. • Correlated outcomes were used to generate estimating equation	**Materials:** • Crysteleye spectrophotometer. • Dentals unite chairside lamp. **Measuring sight:** Maxillary central incisor (cervical, middle, and incisal).	- MCDM mean = 5.228, and the CI= 4.6598-5.8615. - Examiner 1 confidence limits were: 4.6598, 5.8615. - Examiner 2 confidence limits were: 4.6727, 6.4257. - Body confidence limits were: 3.9332, 5.500.

	Using an Intraoral Spectrophotometer, (Witkowski *et al*., 2012)	and accuracy of Crystaleye spectrophotometer to measure tooth colour.		techniques to create two general linear models.	**Method:** • Two examiners evaluated tooth colour using Crystaleye spectrophotometer ten times for 50 participants. • 1st colour measurement was done under laboratory situation light condition with natural and artificial light. • 2nd colour measurement was done by the second examiner for all subjects using chairside lamp of the dental unit with the natural and laboratory artificial light.	- Cervical confidence limits were: 4.5128, 6.4257. - Incisal confidence limits were: 4.6317, 6.3673. - Crystaleye spectrophotometer is recommended for clinical application.
7	Clinical Evaluation of a New Software for shade matching, (Culic *et al*., 2015)	Clinical evaluation of TooDent v1.0 software to measure tooth colour from digital images	Digital	• ΔE colour differences between VITA Easyshade spectrophotometer and the TooDent V 1.0 software was recorded. • The correlation between the two types of measurements were assessed using Pearson, Spearman, and Kendal correlation coefficients.	**Materials:** • Nikon D600 camera. • Nikon AF-S VR 105mm f/2.8G IF-ED lenses • R1 twin flash • Vita EasyShade spectrophotometer. • Vita 3D Master shade guide • TooDent v 1.0 software. **Measuring sight:** Maxillary central and lateral incisors. **Method:**	- The correlation of Spearman was very strong =0.954 (*p*<0.001) between the program and Vita 3D Master codifications. - The correlation of Pearson was very strong =0.973 (*p*<0.001) between the program and Vita 3D Master codifications. - 88% of cases were below the accepted threshold value, ΔE <3.2. - T-Test showed significant correlation for Pearson Spearman, and Kendall. The correlation of L* and

		taken by general practice working conditions.		• Signification of correlations were done using T-Test. • T-Test was also used to compare medium values. • ΔE below 3.2 was considered acceptable.	• Experimental software TooDent v 1.0 was developed in this study. • Two methods of measurements were used in this study. The 1st measurement was done using VITA Easyshade, and the 2nd measurement was done using TooDent v1.0 software. 3D master shades were recorded for both measurements with the CIEL*a*b* readings. • Digital photography was done using standard sittings: - Mode: Manual - Aperture: F22 - Shutter speed: 1/200 - Manual focus - Magnification ratio: 1:2 - White balance: flash 6500 K (colour temperature). - ISO: 100 - Flash mode: Manual ¼ power ratio. - Resolution 4928 x 3264 pixels - JPG - Natural style picture • All tooth photos were taken with a shade tab of Vita 3D	b* axials were stronger than a* axial. - The program that was developed in this study show a good accuracy and can be used with photography for tooth colour measurement. However, to avoid the 12% of values of ΔE that were above the reference value, improvements are required.