

SCIENTIFIC AND ARTISTIC PRINCIPLES OF TOOTH SHADE SELECTION: A REVIEW

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SUMMARY

Modern dentistry is facing growing demands for esthetic tooth-colored restorations, whether in composite, porcelain or acrylic systems. This makes shade selection, on the chair-side and its accurate formulation in the laboratory, the key determinant to the overall success of these restorations. The process of shade selection itself is based on scientific, artistic and physiological principles, which should be properly understood to avoid any shade mismatches and consequent remakes. Hence, the aim of this article was to review the basic principles involved in the shade selection process and present them in an easy-to-understand manner. For this, an electronic search was carried out in PubMed and PakMedinet databases and journal websites, supplemented by a hand search of the published literature and standard textbooks of Prosthodontics to gather all relevant information. It is hoped that this article shall provide useful knowledge to the dental community on the science behind the art of successful shade selections.

Key words: Tooth shade, Principles of shade selection

INTRODUCTION

In modern dentistry, great emphasis is being placed on esthetic restorations by patients and dentists alike.¹⁻³ For these tooth-colored restorations, an accurate and acceptable shade selection on the chair-side and its accurate formulation in the laboratory still remains a demanding task even for the experienced clinicians and laboratory technicians. Routinely, shade selection is performed visually with the help of different ceramic shade guides, which makes this process highly subjective.³⁻⁵

The process of tooth shade selection has been characterized as a science and also as an art by different researchers. Derbabian et al⁶, Hammad⁷, Miller⁸ and Jasinevicius et al⁹ have agreed that shade selection is based on sound scientific principles of color and color science which are at play every time a shade selection is being made. Shapiro and Resk¹⁰ and Seghi et al¹¹ have also found the shade selection process to pose a challenge to the artistic skills of the clinician and laboratory technician through both physiological and psychological factors. It has been recommended by Ahmad¹², Jasinevicius et al⁹ and Carsten¹³ that a thorough knowledge of the applied principles of color and various factors influencing color realization is essential for achieving successful shade selections in routine dental practice.

Without understanding the basics, routine shade selection becomes a mere guess work, whether done on the chair-side or in the laboratory. It is because of this guess work that often shade mismatches are encountered. To improve individual accuracy, it is of paramount importance to have objective knowledge of all factors involved in the shade selection process. Understanding the basic science behind shade selection can help enhance the artistic skills of the clinician or the laboratory technician.

METHODOLOGY

An electronic search of online databases and a hand search of the published dental literature was carried out in October 2009. The search process was systematically divided into 3 phases.

During the first phase, a search was made in the well known PubMed and Pak Medinet databases for the keywords tooth, teeth, shade, color, colour and principles within the title field. Search was limited to english language articles published in dental journals. After filtering out the irrelevant results, a list of approximately 300 article titles including 6 review articles was prepared.

In the second phase, attempt was made to gather as many full text articles as possible from the list devised at the end of the first phase. Articles were downloaded

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from journal websites to which electronic access was available. Many articles were found in a hand search of the journal issues available in respective libraries at Multan Medical and Dental College, Multan, Armed Forces Institute of Dentistry, Rawalpindi, and College of Dentistry, King Saud University, Riyadh. Additionally, some full text articles were obtained from the PASTIC National Center at Quaid-e-Azam University, Islamabad. A total of 100 articles were obtained at the end of the second phase.

During the third phase, all articles and content from standard Prosthodontic textbooks was meticulously reviewed to extract relevant information regarding tooth shades, with special emphasis on the principles involved in the shade selection process.

DISCUSSION

The term “shade matching” has been mentioned routinely in literature and used commonly in practice.^{1,3,14,15} Yet, it is not mentioned in the internationally accepted standard of prosthodontic terminologies i.e. the Glossary of Prosthodontic Terms (GPT). GPT¹⁶ defines this process under “shade selection” or “tooth color selection” as the determination of the color and other attributes of appearance of an artificial tooth or set of teeth for a given individual. Therefore, correct terminology should be adopted in accordance with international standards.

From the onset of the search process, it was noted that a lot of work had been reported on the methods of tooth shade determination, whereas only a handful of researchers had reviewed the principles involved in the shade selection process. As complex as these principles are, an easier way to understand them can be found in the light of the suggestions made by Joiner³ and Alvin.¹⁷ On the basis of their research, the scientific and artistic aspects of the shade selection process have been placed into four main categories: Physical and optical properties of the tooth being viewed; Nature of light to which the tooth is exposed; Assessment of tooth shade by an observer; and Relationship of the tooth to its surrounding colored structures.

Physical and optical properties of the tooth being viewed

The most important physical property related to a tooth's shade is its moisture content. If any tooth is allowed to dry out, its color tends to appear lighter and less saturated.^{18,19} This drying out occurs towards the end of a dental procedure, especially under rubber dam isolation and while making addition silicone impressions. It then takes almost 20–30 minutes for the tooth color to return to its baseline values.^{19,20} Hence it has been recommended to make shade selections at the start of a dental procedure rather than at its end.^{3,17,21}

The optical properties of a tooth result from an interaction between its internal structure (pulp, dentinal tubules and hydroxyapatite crystals) and external features (tooth size, shape and surface texture). Earlier

research by Ten-Bosch and Coops²² showed that dentine was responsible for imparting the basic tooth color, which was further modified by its external features. Recent work by Dozic et al²³ has revealed that the combined effect of all internal structures causes light to be reflected at the surface and absorbed within tooth substance, thereby making a certain tooth shade visible.

In their work on the distribution of tooth shades, Jahangiri et al²⁴ have presented certain phenomena to occur whenever light falls on the surface of a tooth before it is reflected into the eyes of the observer. These include specular transmission of light through the tooth, specular reflection at the surface, diffuse light reflection at the surface and absorption and scattering of light within the dental tissues.

On the basis of these normal physiologic phenomena, Wagenaar and Smit²⁵ and Burkinshaw²⁶ have suggested that the shade selection process is directly related to three essential factors: the tooth being viewed, the light source being used and the eyes of the observer.

Nature of light to which the tooth is exposed

The light source being used is one of the most important and frequently one of the most neglected aspect during shade selection.^{21,27,28} Without this light, color does not exist because an object that is perceived as a certain color (e.g. blue) absorbs all light waves corresponding with all other colors and reflects only those (blue) waves that are perceived as the color of that object.¹⁷ Scientifically, light is an electromagnetic radiation visible to the human eye, having a wavelength from 380–750nm that lies between the shorter wavelengths of ultraviolet light and longer wavelengths of infrared light.²⁹

Different parameters of light are related to shade selection such as its color rendering index (CRI), color temperature and its nature. To go into the details of these parameters is beyond the scope of this paper. By far, the most important parameter to judge a light is its CRI, which is a measure of the ability of a light source to reproduce the colors of various objects being lit by the source.¹⁶ It is rated from 0 to 100. A CRI of 100 gives the best possible rendition of color.³⁰ The nature and quality of light is dependent upon the light source being used, whether it is sunlight or artificial light.

Sunlight remains a major source of energy on earth. However, its distribution and intensity depends on different factors such as time of the day, relative humidity, environmental pollution, weather conditions and season of the year. For instance, light during morning or evening hours is rich in yellow and orange but lacking in blue and green, with its distribution changing under cloud cover.^{13,17,31} Research by Dagg et al³¹ has shown that if light from its source changes (e.g. sunlight under a cover of clouds), it also changes the light reflected from the object, in which case the actual color perceived by the eye is different.

To this end, sunlight has been standardized for shade selection purposes in the form of “northern daylight” i.e. sunlight around the noon hour on a bright day with slight overcast. It has a CRI of close to 100 and is also used as a normal standard for judging light from other sources.¹⁷

In spite of this standardization, the fact remains that sunlight is available only during the day time. Therefore, it is unreliable for dental shade selection purposes because that requires a stable light source in the form of an illuminant.²⁵ This is where the artificial light steps in.

Artificial light is almost universally used in dental surgeries. It can be incandescent (which emits higher concentration of yellow light) or fluorescent (which emits higher concentrations of blue light waves). Neither of these is pure white light.¹⁷ The only artificial light suitable for reproducing the standardized northern daylight is a D65 light source. Unfortunately, the D65 lamps are very expensive and not readily manufactured on a commercial level.²⁵ This leaves room for using fluorescent lighting in dental surgeries and laboratories.

The most commonly used cool white fluorescent tube lights have a CRI of between 50 and 80 and are not recommended for shade selection. The need is for a “color-corrected” fluorescent lighting with a CRI of 90 or above, in line with the recommendations of the American Dental Association.²⁸ Fortunately, this standard can be acceptably reached by using the newer cool white daylight energy saver lamps, which are cheaper and easily available.³² Findings of Azad et al²¹ and Corcodel et al³³ favor these daylight lamps because they improve the shade selection ability of the observer.

Assessment of tooth shade by an observer

Tooth shade assessment involves determination of the target tooth color in the clinic or in the laboratory. This process is based on human vision physiology and its influencing factors.

Tooth shade can be determined either visually with the help of ceramic shade guides^{17,34} or instrumentally with the help of electronic devices (colorimeters, spectrophotometers)^{4,34,35} and computerized techniques (digital image analysis).³⁶ Both methods carry their own merits and demerits. Although the instrumental method provides objective, quantifiable, reproducible and more rapidly obtainable shade selections,³⁷⁻³⁹ but at the moment, it has limited acceptability in clinics⁴⁰ due to increased equipment cost, operational difficulties and lack of standardization. On the other hand, the visual method is subjective and inaccuracies are known to arise due to a variety of reasons. However, it still remains the most commonly used method in clinical dentistry^{3,21,40,41} because it is quick and cost effective, and with proper training and setup a high degree of accuracy is possible.^{3,7,21,42}

Visual shade assessment is based on human vision physiology, whereby reflected light from a tooth enters

the retina to activate the cones, from where electrical impulses are passed on to the optical center in the brain, where an interpretation of color is made.^{17,26} This process is subjective because different individuals can have different interpretations for the same stimulus at different times,¹⁷ and also because the ability to perceive a color and then to distinguish it from other colors (color discrimination) varies greatly from one person to the other, within the same person as well as from patients to dentists.^{3,27,43-47}

Chu⁴⁸ has linked this subjectivity to binocular human vision (both eyes perceiving color slightly differently) whereas Gordon⁴⁹ has linked it to the functioning of cones within the retina (different types of cones get activated in different combinations). Apart from this, some factors have also been suggested to influence the shade selection ability of an individual. These include age, gender, experience, eye fatigue and color vision defects of the observer, in addition to the light source being used, position of the patient, time of the day, background colors and operator fatigue.^{3,25,45}

Wagenaar and Smit²⁵ have found the color vision capability of the eyes to decrease when a tooth is viewed for longer than 10 seconds. The observed color becomes less and less saturated while simultaneously increasing the chroma of complementary colors. To enhance the accuracy of shade selection, it has been recommended by Alvin¹⁷ and Azad et al²¹ to paint the operatory walls in pale blue (complimentary to yellow color of teeth) and to resensitize the eyes to yellow color of teeth by focusing on a pale gray-blue surface immediately before and during the shade selection procedure.

Although Barrett et al⁴¹ have regarded the human eyes to be very discriminating, the fact remains that the eyes and the brain can be tricked in how they perceive color. The black and white Benham disk appears to be highly colored when illuminated and rotated at an appropriate speed. Chu⁴⁸ has related this deceptive color vision to optical illusions and contrast effects whereas Alvin¹⁷ has linked it to metamerism and color blindness.

Clinically significant successive contrast occurs in the form of an afterimage of the first surface that is perceived even when the eyes have physically moved to the second colored surface.⁴⁸ The phenomenon of metamerism is seen when two objects having different spectral reflectance appear to match under a given lighting condition e.g. a yellow object may either reflect yellow light or a combination of orange and green light, both seen as yellow color to the eyes. When the lighting is changed, the metamers no longer match. Such problems can be avoided by confirming the selected shades under different lighting conditions.¹⁷

Color blindness is the inability to perceive differences between some or all colors that other people can distinguish. Upto 8% males and less than 1% females are known to be color blind.⁵⁰ Research by Carsten¹³ and Gordon⁴⁹ has shown that nearly all people suffer from

some level of color vision confusion or color blindness, which can be a serious handicap for dental practitioners, assistants and laboratory technicians. ADA²⁸ has recommended to have an objective knowledge of one's color vision capability. Therefore, all dental personnel should have their color vision tested every 2-3 years during their professional careers.^{19,51} If any vision deficiency is detected, the concerned person should seek assistance when selecting or formulating tooth shades or switch to instrumental method for this purpose.⁵²

Relationship of the tooth to its surrounding colored structures and surfaces

Tooth color perceived by an observer is influenced by other colored structures surrounding the tooth such as adjacent teeth, gingiva, lips, face skin, clothing of the patient and operatory walls.

Anterior teeth usually have slightly different colors according to their position within the arch e.g. maxillary central incisors are the lightest teeth whereas the canines are relatively redder, yellower and more saturated with color. Likewise, maxillary anterior teeth are slightly yellower as compared to mandibular anterior teeth. These fine differences in color of adjacent teeth can make selecting and finalizing tooth shade a testing procedure even for the experienced professionals.^{3,41,53,54}

Teeth are also known to possess a color gradation from the cervical area to the incisal area. According to Schwabacher et al⁵⁵ and O'Brien et al,⁵⁶ the cervical color is modified by scattered light from the gingiva whereas the incisal color is most often translucent and affected by its background. Therefore it has been recommended by different researchers that only the middle third of a tooth best represents its shade.^{3,24,55}

However, fabricating an anterior restoration from a single shade is in itself going to result in shade mismatch because tooth color tends to change from cervical area to the incisal edge. Hence, tooth shade mapping has been proposed. A practical approach is to divide the crown into two, three or four equal portions, and then shade should be selected separately for each portion. Readings can be plotted on a shade distribution chart, which also allows to copy certain surface characteristics into the fabricated restorations.¹⁷ However, Barrett et al⁴¹ are of the view that it is very difficult to concentrate on a small area of a non-homogenous tooth surface and so shade mapping becomes a testing procedure even for the experienced professionals.

Gums and lips form the soft tissues immediately adjacent to the teeth and can influence the apparent color through the phenomenon of contrast. As has been reported, the subjects' perception of tooth whiteness, health and attractiveness is greatly influenced by the color of the adjacent lips and gums.³ Lip color can be altered through the use of lipstick. Presence of dark colored lipstick creates the illusion of whiter teeth. Hence it is always recommended to ask the patients to

remove any lipstick before tooth shade selection is performed.^{3,17,21}

Classically, it is believed that individuals with darker skin colors have lighter shades of teeth, which is explained by the illusion of greater contrast between skin color and tooth shade.^{21,24} Skin color can serve as a useful guide for the selection of tooth shade in removable and complete denture prostheses as well as in full-mouth rehabilitations to achieve a pleasing natural appearance, especially in the elderly.^{24,57}

Clothing worn by the patient and color of operatory walls can create contrast effects during the shade selection process. Therefore, it has been recommended to drape all bright colored clothing prior to shade selection while the operatory walls should be painted in a neutral (pale gray-blue) color.^{3,17}

CONCLUSION

From the preceding discussion, it is clear that tooth shade selection is a highly complex process that requires an interaction of scientific, physiological, psychological and artistic factors for an accurate outcome. Scientific principles related to light and color play a key role in determining the tooth shade perceived. However, the perception of color is dependent upon human vision capabilities which can alter the shade captured by the eyes or its image made in the brain. Any vision-related deficiency can seriously affect the reliability of the shades selected or formulated. Furthermore, artistic qualities of an individual can modify the way a shade is observed. The need is not only to have proper training and setup for the routinely used visual method but also to properly understand the various factors involved and their influence on shade selections. Only in this way one can approach this process not as a mere guess work but as a scientifically and technically selected tooth shade. This can ensure reliable, repeatable and accurate shade matches on a day-to-day basis.

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