Fundamentals of COLOR

Shade Matching and Communication in Esthetic Dentistry | Second Edition

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Fundamentals of Color: Shade Matching and Communication in Esthetic Dentistry, Second Edition

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Alessandro Devigus

Rade Paravina

Adam J. Mieleszko

To my teachers: Dr Ralph A. Yuodelis and Dr Robert R. Faucher

—SJC

To my wife, Beatrice

—AD

To my family for their love and support

—RDP

To my loves, Inga and Adrian, for their everyday support and inspiration

—AJM

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FOREWORD TO THE SECOND EDITION

I have always believed that *why* we do what we do is just as important as *how* we do what we do. Knowing *why* helps one understand a multitude of *hows* with regard to color and esthetics. When this method of education is coupled with a progressive approach to learning, a powerful tool for understanding is created. Although some may believe that including physics, chemistry, psychology, and psychosocial information in a book on color science and esthetics is superfluous, the authors clearly do not, and I absolutely agree with them. I want to emphasize the importance of this basic tenet in learning a subject in depth. Taking this approach makes something good even better.

The addition of Dr Rade Paravina’s expertise in both the basics of color as well as the future of color education makes this edition more effective in color teaching and in the use of color for creating highly esthetic dental restorations. The staged and step-by-step approach is a proven method for teaching a subject that is simultaneously fun, exciting, and yet highly complex. Much like learning a piece of music requires hearing the music rather than just seeing the notes on paper, color requires as many sensory cues as are necessary for one to learn the subject. The updated electronic approach to learning, matching, and seeing color adds an extra dimension to this edition.

This second edition delves more deeply into digital photography and material selection. As the dental profession advances, it is necessary that educators and clinicians follow suit and provide additional materials to help others use that technology. The authors have taken the necessary steps to include such information in this edition.

When asked by students, “What’s new in dentistry?” and “Why should I become a dentist?” I answer that dentistry is a dynamic profession, developing exciting new materials and methods for treating patients with ever-improving technology that has the clear ability to change people’s lives. Stephen J. Chu, Alessandro Devigus, Rade D. Paravina, and Adam J. Mieleszko have shown that they can provide just that motivation and excitement.

This is a welcome and stimulating addition to color education in dentistry. It encompasses a variety of esthetic dentistry procedures and is a clear guide to integrating additional dental technology, whether digital photography or spectrophotometry, into everyday dental practice.

Stephen F. Bergen, DDS, MSD

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FOREWORD TO THE FIRST EDITION

In the span of my dental career, dentistry has made spectacular improvements in mimicking the natural colors of teeth with restorative materials. In the early 1960s, metal ceramics presented exciting new possibilities for tooth colors, as well as soft tissue response, longevity, and esthetics. In general, clinicians have had little understanding about color, and even less has been taught. Several contemporary clinicians contributed enormously to our knowledge of the art and science of color. There was Bruce Clark in the 1930s and then Robert C. Sproull, Jack D. Preston, and Stephen F. Bergen in the 1970s.

John W. McLean, a giant in the dental profession, introduced us to high-strength all-porcelain restorations with aluminous porcelain in 1965. The bar was raised for color in dental porcelain. Artistic laboratory technicians made immense progress with internal colors and the management of opacity and translucency. By the 1990s, adhesive dentistry, composites, and myriad all-ceramic materials gave us the artistic capacity to reproduce the colors and light response of natural teeth.

The authors of this text, Stephen J. Chu, Alessandro Devigus, and Adam J. Mieleszko, have made an outstanding contribution to the practice and theory of color management in contemporary dentistry. Updating is a way of life, and the flood of new materials and techniques makes this text all the more valuable to students, general practitioners, and specialists. A concise introduction to color theory and how it applies to dentistry is followed by important information about elements affecting color to aid the clinician and technician with problem solving. Special attention has been given to shade matching with a step-by-step protocol. Direct composites and layering techniques receive careful consideration. In particular, the chapter on digitized shade-matching technology provides the reader with valuable insight into color measurement technology and its applications for laboratories and patients. Finally, an extensive presentation of clinical cases from single anterior crowns and composites to multiple anterior restorations is used to illustrate the full extent of the text.

It should be noted that the science of color in dentistry always requires skill by the user. In particular, there is a lack of standards in the production of dental ceramic frits. The variables of hue, value, chroma, and translucency from batch to batch and between companies require unusual artistic skills from ceramists to produce prescriptive shades. Perfect shade measurement will not produce comparable shade matching unless realistic standards are established by manufacturers. In the meantime, we need to be especially empathetic to dental laboratories until the science and art of color in dentistry come together.

The authors have produced a text on shade matching and communication that fulfills a genuine need. I found it to be a refreshing approach to color and am especially privileged to write this foreword.

Lloyd L. Miller, DMD

PREFACE TO THE SECOND EDITION

Since the first edition of *Fundamentals of Color* was published, many of the tools and materials used in color dentistry have undergone significant improvements, and a number of new products have been introduced. As technology continues to evolve, so too does the range of digital shade-matching systems available. Technological advances in other industries, such as photography and lighting, and in other subsets of dentistry—eg, intraoral imaging (CAD/CAM) and teeth whitening—have helped to make the protocols of color dentistry more accurate. The prominence of color dentistry in the general dental community has been raised by the formation of the Society for Color and Appearance in Dentistry (SCAD) and the *Journal for Color and Appearance Dentistry*; accordingly, the amount of clinical research has also increased, which is extremely important for the expansion of any field.

Fundamentals of Color, Second Edition strives to consider and reflect these new changes. It opens with a critical new chapter on color education and training, which is appropriately followed by sound discussions of color theory and factors that influence perception of color. The book pragmatically reviews the standard recommended protocols for conventional and technology-based shade matching; these chapters culminate in a straightforward, step-by-step protocol that incorporates both the most current and most respected techniques for successful color reproduction. New chapters on digital photography and material selection supplement these protocols and are valuable resources on two topics that strongly influence in shade matching and color communication. The book concludes with 12 in-depth clinical case presentations covering a variety of situations commonly encountered in daily practice. Like the previous edition, this textbook is written in a logical, succinct manner that simplifies the study of color and helps readers understand, qualify, and quantify shade so they can more easily and accurately communicate with colleagues and lab technicians alike.

Acknowledgments

We would like to thank X-Rite, Inc, Olympus, and MHT Optic Research for their outstanding collaboration on dental color-measuring devices. We are grateful to Vita Zahnfabrik and Vident for information on several of their new products and for the support we received for SCAD. We acknowledge SCAD for advancing multidisciplinary collaboration and discovery among industrial and institutional researchers, clinicians, lab technicians, and others, and for creating and implementing research, educational, and training programs on color and appearance for dental professionals and students. We would also like to thank the Heraeus Kulzer Company for providing the high translucency, synthetic feldspathic ceramic material used in the case restorations and give a special thanks to the staff of Quintessence Publishing Co, who made this book a reality.

Additionally we would like to thank Dr Shigemi Ishikawa-Nagai and Dr John Da Silva at Harvard University for their contributions to the clinical cases and Dr Wolfgang Bengel, whose contribution not only to this book but to the specialty of dental photography is an inspiration to practitioners globally. We are indebted to Dr Didier Dietschi, whose research in direct restorative composite materials has set the standard in composite resin color science, and his colleagues Dr Stephano Ardu and Dr Ivo Krejci for the direct restorative case report they contributed to this book.

Thanks also to Kendall Beachman, Assistant Dean at New York University College of Dentistry, Dr Dennis Tarnow at Columbia University, and Dr John M. Powers at Dental Consultants, Inc for their motivation, inspiration, and ongoing support in dental education. Finally, our appreciation goes to Jason Kim, CDT, for imparting his knowledge and skill in the fields of color and translucency.

PREFACE TO THE FIRST EDITION

The study of color is an integral part of esthetic dentistry. If the color of a restoration is off—even slightly—the mistake can be glaringly evident; it looks fake, and the patient is unhappy. Obviously, this is an undesirable result.

Unfortunately, color is also tricky. Slight variances in shade play with our eyes, our minds, and, ultimately, our dentistry. The illumination in the dental treatment room, optical illusions, color blindness, nutrition, and fatigue are among the dental professional's ongoing obstacles to successful shade matching. It is necessary to understand these challenges and the basic mechanisms of color in order to achieve consistent esthetic shade results. However, most of the dental literature on color theory does not improve the reader's understanding; rather, it further compounds the complexity. Moreover, color education seems to be absent within the dental school curriculum. What is needed is a resource that distills all the data and breaks down the abstract science of color into the essential details. This text was written to simplify the study of color and help readers quantify and communicate shade easily and accurately.

Fundamentals of Color first explains the basics of color theory, then illuminates the factors that can affect the perception of color. Next, the recommended protocol for conventional and technology-based shade matching are detailed separately. Finally, an approach combining both methods is outlined in chapter 5, providing the reader with a technique that almost ensures an accurate shade match the first time, every time. Throughout the text, there are hints and tips to enhance the reader's comprehension and clinical results. Also included is an appendix describing clinical cases in which the recommended protocol was followed to achieve esthetic and predictable results.

This book is intended for anyone seeking to gain a better understanding of the complexities of shade matching, advance their esthetic dentistry skills, and increase the natural quality of their restorative work. Although we are all health care providers first, we are also artists. With a good working knowledge of color, your artistry will become as natural as your dentistry.

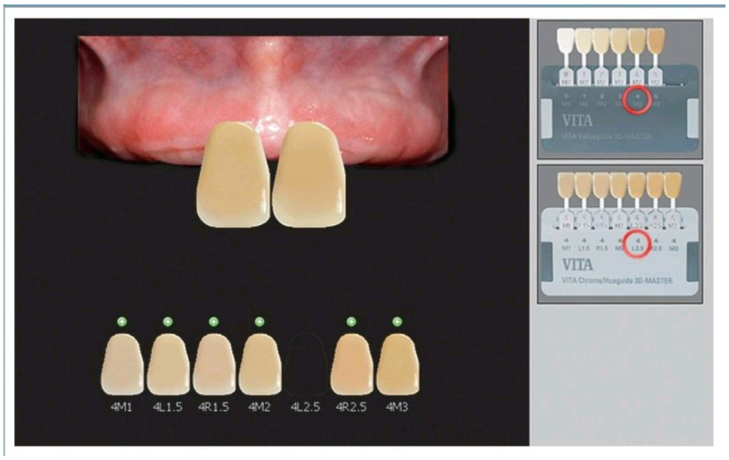
Without the support, dedication, and passion of many people, this book would not have been possible.

First, we would like to thank the people at X-Rite, Inc: Mike Ferrara, Tom Nyenhuis, Kevin Aamodt, Jim Overbeck, and Shannon Gary, who greatly contributed to our knowledge in the field of color science. We would also like to recognize Dustin Ewing from MHT Optic Research for explaining the use of the SpectroShade system. Thanks to Dr William Devisio and Bernal Stewart from Colgate-Palmolive Co for the present and future collaborative clinical research projects in the area of vital bleaching. To the Heraeus-Kulzer-Jelenko Co, especially Gerrit Steen, Chris Holden, Dr Mark Pitel, and Dennis Fraioli, thank you for providing the beautiful synthetic ceramic material used in the case restorations. We would also like to recognize Steve Wright, from Lanmark Group, who helped distill our thoughts and ideas in the writing of this body of knowledge. Special thanks to the staff of Quintessence Publishing Co, who made this book into a reality.

We would also like to thank Dr Irfan Ahmad, whose contributions not only to this book but also to the specialties of fixed prosthodontics, esthetic dentistry, and dental photography have been an inspiration to practitioners globally. We are indebted to Dr Didier Dietschi, whose research in direct restorative composite materials has set the standard in resin composite color science, and his colleagues, Dr Stephano Ardu and Ivo Krejci, for the direct restorative case report they contributed to this book. Our appreciation also goes to Drs Stefan Paul and Ed McLaren, whose previous and ongoing studies in the field of technology-based color systems have considerably increased our knowledge base. We would also like to thank Giordano Lombardi, CDT, whose technical skills, techniques, and working relationship have solidified the highest standard of excellence in the area of esthetic restorative dentistry in Switzerland.

Special thanks to Dr Galip Gürel (Istanbul, Turkey), whose textbook on ceramic laminate veneers opened our eyes to the world of cosmetic restorative dentistry and color. Thanks also to Assistant Dean Kendall Beachman and Dr Dennis Tarnow at New York University College of Dentistry for their motivation and inspiration. Finally, our appreciation goes to Jason Kim, CDT, for imparting his knowledge and skill in the fields of color and translucency.

CHAPTER 1 COLOR EDUCATION AND TRAINING



In this chapter:

- Cultivating the skill of shade matching
- Currently available shade-matching publications and programs

Many factors influence our ability to achieve accurate shade-matching results, including subjectivity, shade-matching tools, materials, methods, and conditions. Nonetheless, the importance of color education and training should not be underestimated, as S p roull noted in 1973: “The technology of color is not a simple matter that can be learned without study; neither is it a complicated matter beyond the comprehension of dentists.”[1] Color appearance is frequently of critical importance to the final outcome of dental restorations and their acceptance by patients. This is why education and training should be the first step of a process that should result in the predictable and enhanced esthetic outcome of dental restorations.

Cultivating the Skill of Shade Matching

Successful musicians, painters, and other artists are both gifted and well educated in their craft, and yet they continue to practice and improve their skills. In contrast, little effort is made to assess whether the average dental professional has an eye for shade matching. Moreover, education on color is frequently not even part of the undergraduate or graduate dental school curriculum.[1–3] Years of shade-matching experience practiced under inappropriate conditions, using inadequate tools and methods, can hardly be called color training. The literature shows that dentists often overestimate their color-matching and reproduction abilities. When asked to match 16 corresponding pairs from two Vitapan Classical shade guides using the visual method, the pre- and postdoctoral participants correctly matched only 50%.[4] In another study, which closely resembled clinical dentistry in that there was no exact match, the observers’ choice was the second or third best match.[5]

Several surveys have been conducted on color education. The first one, in 1967, revealed that only

3 institutions (of the 115 institutions that responded) offered a color science course, and only 2.3 classes, on average, referred to color topics.[1] In another survey, core curriculum and elective courses on color were taught at 26% and 17%, respectively, of the 69 responding schools.[2] A third survey related to teaching of color in predoctoral and postdoctoral dental education was conducted in 1988. Responses were received from 138 institutions.[3] The mean number of hours devoted to color topics was 6.6, and 50% of the schools reported a lack of a color-balanced environment. In addition, 85% of respondents believed that there was a need to develop a new, systematic shade guide. It was concluded that additional efforts should be made regarding the study, research, and application of color science in the dental profession, particularly in undergraduate education.

Currently Available Shade-Matching Publications and Programs

Several multimedia color education and training programs are now available (Table 1-1). Each program has its own unique features, but they all are designed with the same intention: to educate/train dental professionals in color matching. A brief description of each program is provided below.

The book *Esthetic Color Training in Dentistry* and its supplementary color-training exercises on CD-ROM are designed to be used by dental professionals, educators, and students. The training program consists of an introductory set, a training set, and an advanced set. The introductory and training sets each consist of three groups of exercises, which progress from easy to difficult. Each of these six different sets consists of 25 small squares and arranging sets that test shade matching based on differences in value, chroma, or hue, and, for further challenge, differences based on all possible pairs of color dimensions (value/chroma, value/hue, and chroma/hue). The advanced set (Fig 1-1) contains 15 rectangles with color differences that originate from all three color dimensions simultaneously.[6] The software records both first and highest scores and includes a "reset score" option that enables repetition of the exercises or addition of other users.

TABLE 1-1 Shade-matching publications and programs

	Format	Publisher	Features
Esthetic Color Training in Dentistry	Book and CD-ROM	Mosby	Interactive CD-ROM enhances understanding of the text.
Toothguide Trainer & Toothguide Training Box	Online software and training box	Vita Zahnfabrik	Easily accessible digital practice can be supplemented by physical shade tabs.
A Contemporary Guide to Color & Shade Selection for Prosthodontics	DVD	American College of Prosthodontists	Educational tool; good for building foundational knowledge.
Dental Color Matcher	Online software	Vita Zahnfabrik	Comprehensive training software and video available free online.

Fig 1-1 *Color Training Exercises, advanced set.*

Another popular multimedia program is the Toothguide Trainer software and Toothguide Training Box (Vita Zahnfabrik) (Figs 1-2 and 1-3), which are parts of the color-training program developed by Jakstat.[7] The exercises in the training software are essentially the same as those in the training box; both utilize 26 shade tabs from the Toothguide 3D-Master (Vita Zahnfabrik). The software uses the images of tabs, whereas the training box uses physical shade tabs, along with color-corrected light and computer support. The program is designed in accordance with the three-step method recommended for 3D shade-matching (value-chroma-hue selection). A total of 4, 8, and 15 correct matches, respectively, are needed to pass steps 1 (value selection), 2 (value-chroma selection), and 3 (value-chroma-hue selection). After that, the user proceeds to 15 value–chroma–hue tasks in the final exam.

A Contemporary Guide to Color & Shade Selection for Prosthodontics is a DVD published by the American College of Prosthodontists.[8] It is a predominantly educational tool with 63 figures and 12 instructional videos that complement the text.

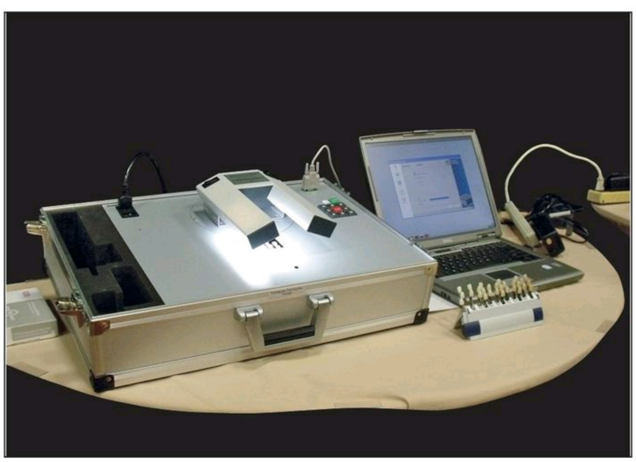


Fig 1-2 *Toothguide Training Box with the associated computer program.*

Fig 1-3 Toothguide Training Box with working area illuminated by color-corrected light.

In the first part, general color topics are addressed: color triplet, defective color vision, color mixing, the color wheel, a description of color and the relationship between the dimensions of color, and two color notation systems: Munsell and CIELAB. The second part of the text is related to the color of human teeth, dental shade guides, and digital shade selection.

The DVD also includes detailed guidelines for visual shade selection and suggested procedures and discusses:

- Light source parameters
- Type, amount, and location of lighting
- Metamerism
- Surrounding colors
- Shade-matching distance
- Time and length of shade selection
- Patient position and involvement
- Tooth condition, including light transmission and surface characteristics (texture and gloss)
- Translucency and transparency
- Dentin and gingival shade selection

Shade verification and communication with the dental laboratory technician using diagrams and digital images are also elaborated.

Finally, Dental Color Matcher (Vita Zahnfabrik) is a free online education and training program hosted through the website of the Society for Color and Appearance in Dentistry (www.scadent.org/dcm).[9] This program is a combination of color matching exercises and a didactic video.

The first of the onscreen exercises, "Closest match I," asks the user to determine the best match to four target shade tabs using Linearguide 3D-Master tabs (Fig 1-4). Afterward, the 25-minute video provides information on the role of color in contemporary esthetic and cosmetic dentistry, shade-matching skills and success of dental professionals, color dimensions and the color of human teeth, and color-matching methods used in dentistry. The video particularly addresses influences on the visual method, such as years in practice, sex, education and training, color-matching conditions, as well as techniques to achieve predictable success with visual shade matching.

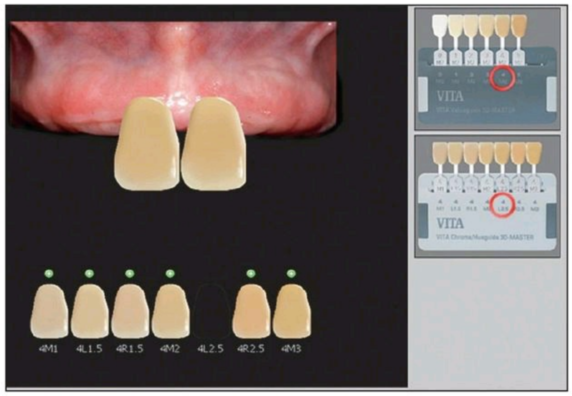


Fig 1-4 *Dental Color Matcher. "Closest match" exercise.*

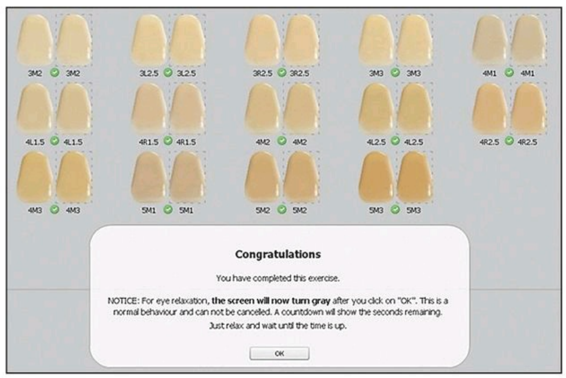


Fig 1-5 *Dental Color Matcher. "Matching pairs" exercise: 14 darker pairs of shade tabs successfully matched.*

After the video, users are prompted to "Matching pairs" exercises to match 29 Linearguide 3D-Master pairs (15 lighter pairs and 14 darker pairs) (Fig 1-5). The subsequent "Exact match exercise" is identical to the initial "Closest match" exercises, except that there is an exact match to each tab. The next step is a quiz in which users answer 12 multiple-choice questions related to the information provided in the video. After completing the program, users can fill out a survey, rate the program, and list its strengths and weaknesses. Upon request, dental professionals can obtain 2 continuing education hours, while all users obtain a diploma issued by the Society for Color and Appearance in Dentistry upon program completion. Dental educators who want to use this program for undergraduate or postgraduate teaching or continuing education for dental students or professionals are encouraged to request a project code (by sending an email to dcm@scadent.org), which will allow them to independently access the results for each enrolled participant.

Conclusions

Significant advances have been made in color education and training in dentistry. New books and other types of publications—training programs on CD-ROM, online programs, and those that utilize physical shade tabs—are currently available. Based on purpose and scope, all of these publications and programs offer valuable color education and/or training. Online programs provide free access to a wide range of users (clinicians, dental technicians, dental educators, students, and researchers) seeking color education and training. Knowledge and skills acquired through these programs complement the skills of dental professionals and provide an appropriate foundation for their work.

Summary

- Shade-matching results can be improved through color education and training.
- Most color education and training programs are relatively new, and unfortunately few are currently incorporated into undergraduate or graduate dental education. Therefore, the implementation of available programs and the development of new tools should be the next step in color education and training in dentistry.

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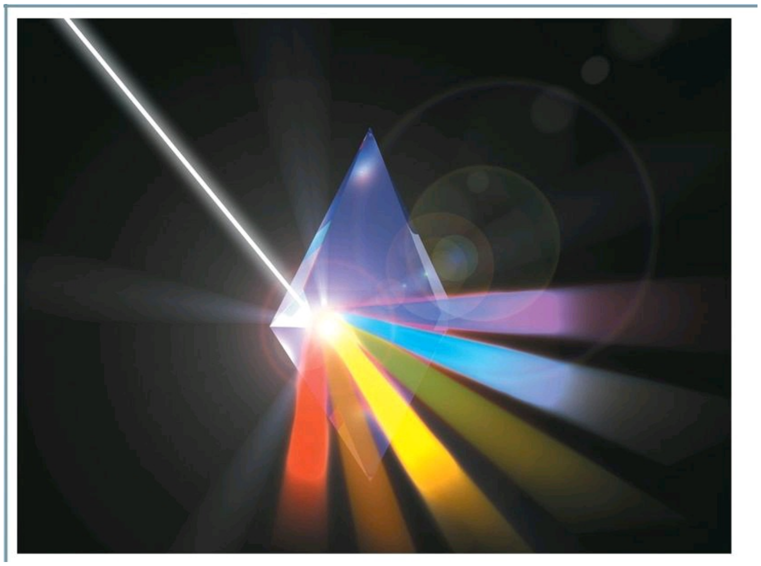
CHAPTER 2 COLOR THEORY



In this chapter:

- The physics of color
- Color reproduction
- Color in dentistry

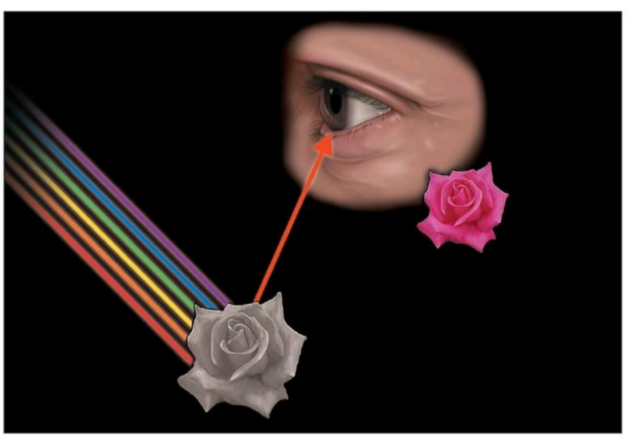


Fig 2-1 *The wavelengths of light reflect off the object (a rose), resulting in the perception of color (pink) by the viewer.*

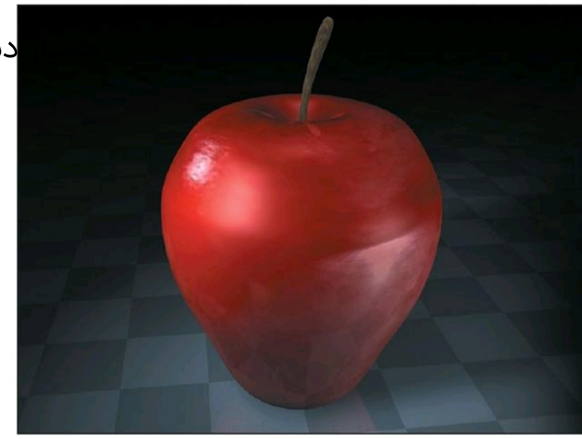


Fig 2-2 *A red apple. Its specific color description is subjective and debatable, stemming from an emotional or visceral response.*

Many have long pondered the question: If a tree falls in the woods and there is no one there to hear it, does it make a sound? In color theory the question becomes: If the petals of a rose are pink and there is no one there to view them, are they actually pink? According to color theorists, the answer is no. The reason for this surprising answer is that in order for a color to exist, there needs to be an interaction between three elements: light, an object, and a viewer (Fig 2-1). If all three elements are not present, color as we know it does not exist.

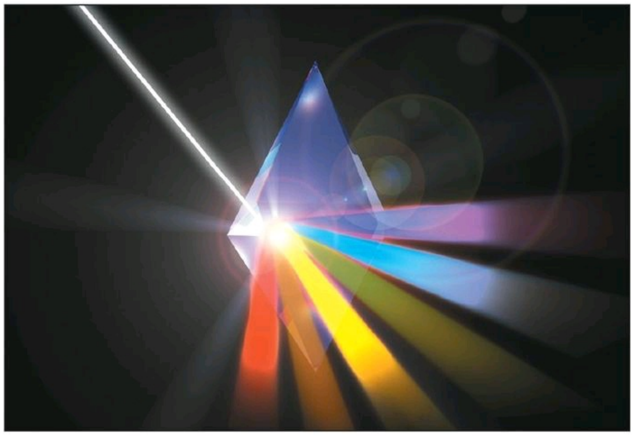
Color is best described as an abstract science. Color appeals to the visceral and emotional senses. Color is personal; each individual will view the same object differently. Take, for example, the apple shown in Fig 2-2. Most would define its color as red; others might take it a step further and describe it as cranberry red or vibrant ruby red. It is often difficult to come to a consensus based on visual assessment alone. There are numerous factors that influence an individual's color perception, including lighting conditions, background effects, color blindness, binocular differences, eye fatigue, age, and other physiologic factors (see chapter 3). But even in the absence of these physical considerations, each observer will interpret color differently based on his or her past experiences with color and resulting color references. Each individual also verbally defines an object's color differently.[1–9]

However, there are quantifiable aspects of color that are important for the dental practitioner to understand. Basic knowledge of how color is perceived and reproduced will aid the clinician in evaluating and matching shades in the dental practice.

The Physics of Color

Although color is generally perceived as an art form, there is a true science behind color theory. Isaac Newton was the first to break down the physics of color. He found that a beam of white light could be separated into component colors, or wavelengths, by passing it through a prism (Fig 2-3). Newton described the resulting continuous series of colors as a spectrum, and named these colors in the following order: red, orange, yellow, green, blue, indigo, and violet, as represented by the commonly used mnemonic association Roy G. Biv. These wavelengths are perceived by the three types of color receptors (called cones) in the human eye as variations of red, green, and blue light. The human eye can perceive only these wavelengths of light, hence the term *visible light spectrum*. In physical terms, the wavelengths of visible light range from approximately 400 to 700 nm (Figs 2-4 and 2-5). Each hue is accurately defined by its wavelength or frequency[1] (Table 2-1).

Fig 2-3 Dispersion of light through a prism breaks the light up into its component colored frequencies, which are called wavelengths.



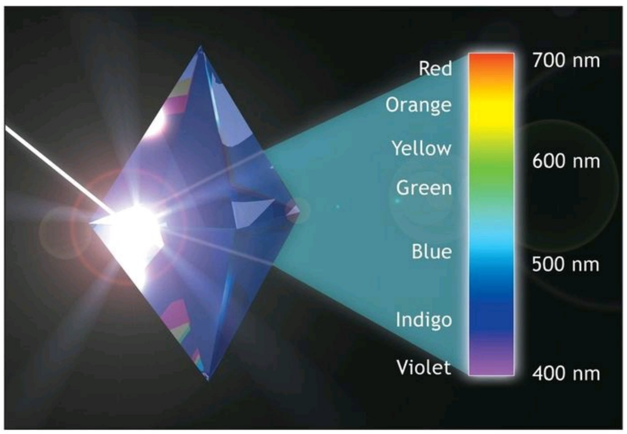


Fig 2-4 The wavelengths of visible light range from 400 nm (violet) to 700 nm (red).

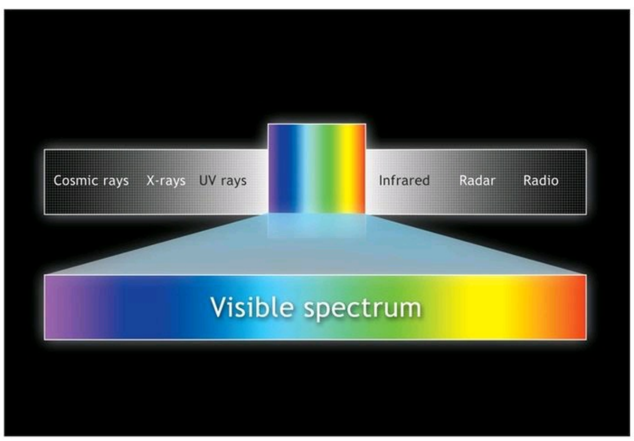


Fig 2-5 The visible light spectrum relative to the whole electromagnetic spectrum.

***TABLE 2-1** Wavelengths of colors*

Color	Wavelength (nm)*
Red	650–800
Orange	590–649
Yellow	550–589
Green	490–539
Blue	460–489
Indigo	440–459
Violet	390–439

*1 nm = 0.000001 mm.

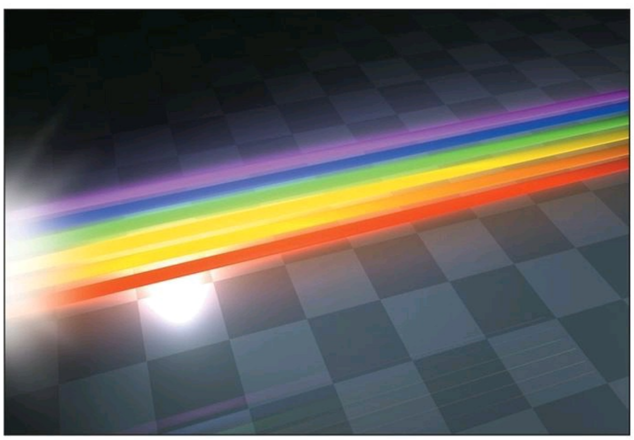
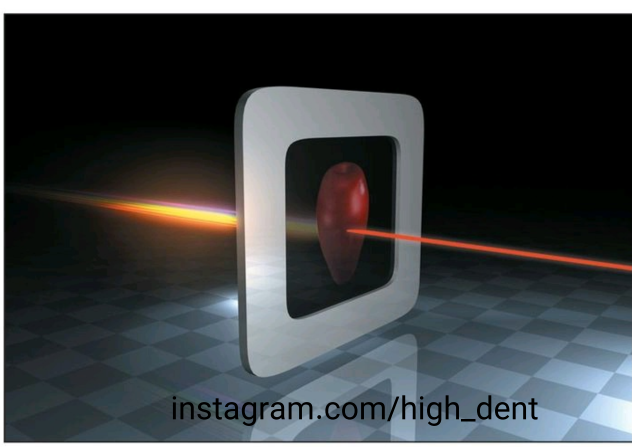


***Fig 2-6** Emission of light.*



Newton's significant breakthrough in the study of color science shifted attention to the light source.[10] His observation was simple: White light contains all colors. If an object appears to be a particular color, this means that the light reaching our eyes when viewing that object has somehow been changed by the object. In other words, it is the interaction of the light with the object that allows perception of color. Therefore, without light, there would be no color.

The basic process of color perception can be described as follows. Light is *emitted* from a light source. This light may reach the eye directly, or it may either strike or pass through an object. If the light interacts with an object, some of the light is *absorbed* by the object. The wavelengths that are not absorbed (ie, those that are reflected, transmitted, or emitted directly to the eye) are perceived by receptor cells (ie, rods and cones) in the eye and recognized by the brain as a specific color. The individual components of this process are described in more detail below.

Emission

Emission of light from a source occurs through a chemical or physical process (Fig 2-6). Every process releases more light at certain wavelengths than at others. To create perfectly white light, a light source would have to emit exactly the same amount of each wavelength. In some cases, emissive objects are intended to produce specific colors. These objects, such as computer monitors, produce color by emitting light with distinct wavelength compositions of red, green, and blue light. This process is discussed in greater detail later in this chapter.

No light source can emit perfectly white light, ie, exactly the same amount of each wavelength. This affects color perception since there are only certain wavelengths (colors) being produced to interact with an object, which explains why the same object will appear to be different colors when viewed using different light sources (see chapter 3).

Transmission and absorption

Transmission occurs when light passes through a transparent or translucent material, such as a slide or film (Fig 2-7). If light encounters molecules or larger particles in the material, some wavelengths of light will be *absorbed*. The number of light rays and the specific wavelengths (colors) that are absorbed are determined by the density and makeup of the material the light travels through; the wavelengths that are transmitted (referred to as *spectral data*) compose the color that is perceived. If the material is completely transparent, all light is transmitted, and the color white is perceived. If the material is completely opaque, all light is absorbed, and the color black is perceived. In most cases, however, some of the wavelengths (colors) are absorbed and others transmitted. If this occurs, the color that is perceived corresponds to the wavelengths that are transmitted. For example, if a material absorbs red wavelengths and transmits green and blue wavelengths, a combination of green and blue (referred to as *cyan*) is perceived.

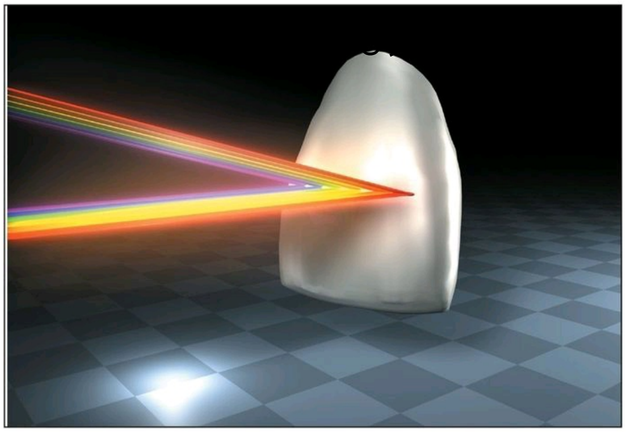


Fig 2-8 *Reflection of light.*

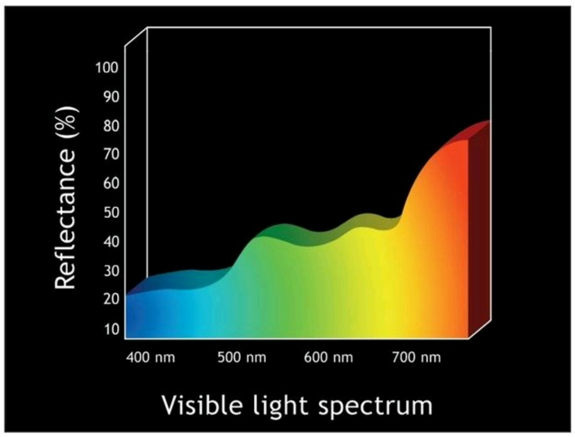


Fig 2-9 *Diagram showing the percentage of light wavelengths that are reflected by an object. The percentage is measured every 10 nm along the visible light spectrum (400 to 700 nm). The resulting pattern is called a spectral curve and is analogous to the color fingerprint of an object.*

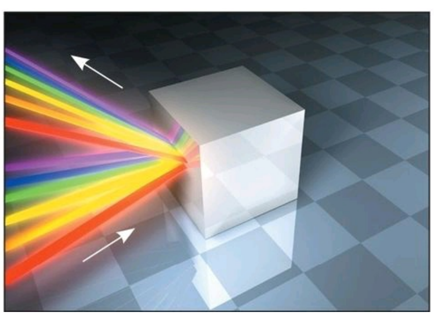


Fig 2-10 *A perfectly white object would reflect all wavelengths of light.*

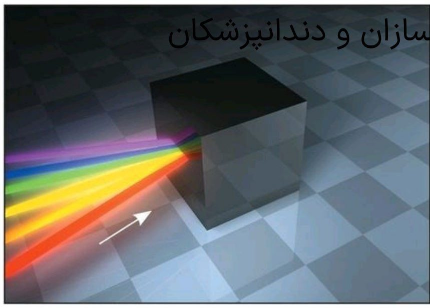


Fig 2-11 A perfectly black object would absorb all wavelengths of light.

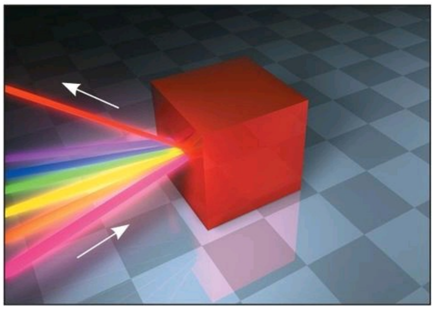


Fig 2-12 A red object reflects red light and absorbs all other wavelengths.

Reflection and absorption

Reflection occurs when light rays strike a solid object, such as an apple or a photograph, and then bounce off of it (Fig 2-8). Depending on the molecular structure or density of the object or medium, certain wavelengths (colors) may be *absorbed* rather than reflected. The wavelengths that are reflected compose the color that is perceived (Fig 2-9). Theoretically, an object that reflects all light would be perceived as white (Fig 2-10), and an object that absorbs all light would be perceived as black (Fig 2-11). In most cases, however, the object absorbs some wavelengths (colors) and reflects others (Fig 2-12). If this occurs, the object is perceived to be the color of the wavelengths that are reflected. For example, an object that absorbs green wavelengths but reflects red and blue wavelengths is perceived as a combination of red and blue (referred to as *magenta*).

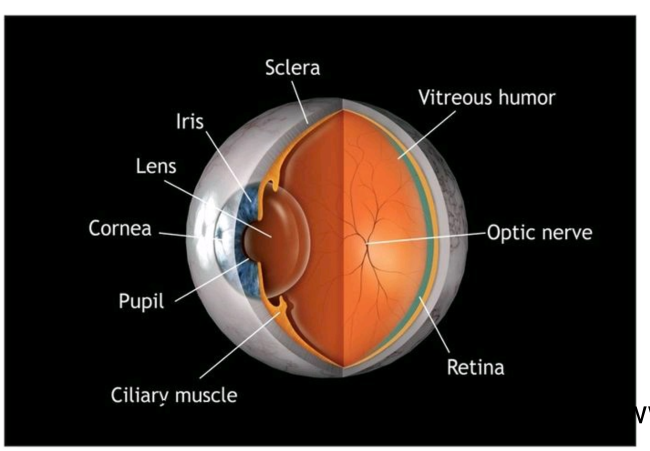


Fig 2-13 *The retina of the eye contains three types of cone cells responsible for color perception, as well as rod cells, which are responsible for perception of lightness and darkness.*

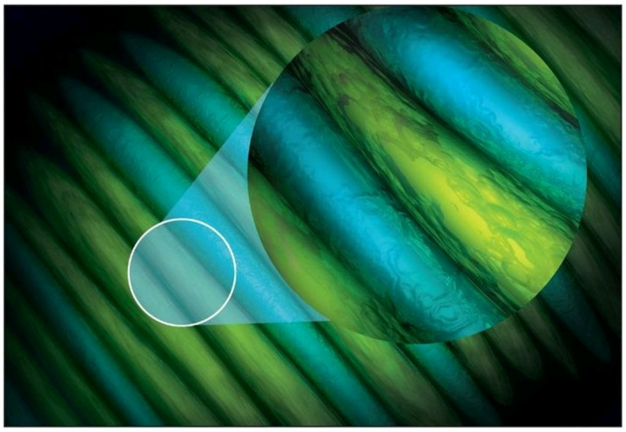


Fig 2-14 *There are fewer cone cells (aqua) in the retina than there are rod cells (green).*

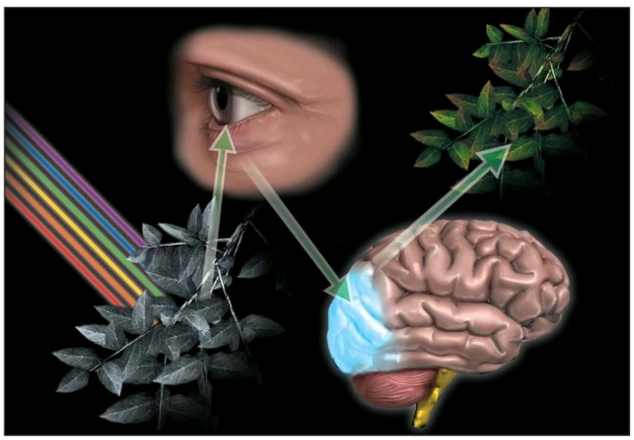


Fig 2-15 *Color perception occurs in the brain.*

Perception

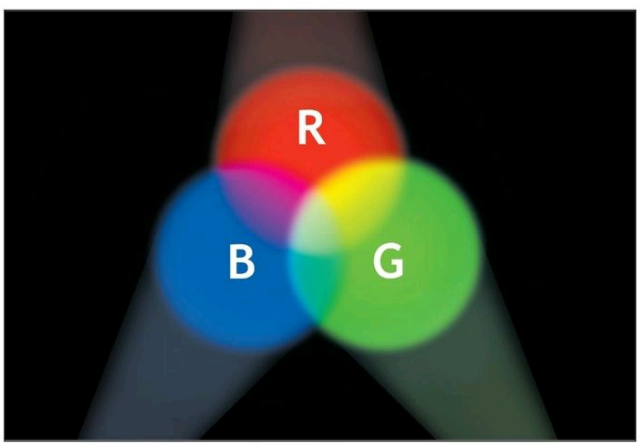
The wavelengths that reach the eye, whether by emission, transmission, or reflection, are received by the sensory cells on the retina called the *rods* and *cones* (Figs 2-13 and 2-14). The rods perceive the brightness of the color, ie, the intensity of the light rays reaching the eye. The cones perceive the *hue*, ie, the color. As discussed previously, the human eye contains three different types of cones, each one responsive to wavelengths approximating the colors red, green, and blue, respectively. Variations of these wavelengths will stimulate each cone at different intensities. The cone cells then send signals to the brain, which translates the signals into colors (Fig 2-15).

The key point to understand is that the wavelength pattern that is perceived by the eye is the color's fingerprint.[1] This fingerprint is formulated from spectral data gathered from the wavelengths of light reflected from an object. It is plotted, in reference to percentage of reflectance and wavelength interval distribution, as a spectral reflectance curve (see Fig 2-9). Therefore, in Fig 2-2, the apple itself is not red; the color that is perceived is only in the form of reflected wavelengths, and the color we sense and remember as red really exists only in our minds (Table 2-2).

TABLE 2-2 Psychophysiologic realities of color perception

Mode of perception	Psychophysiologic reality
Physical	Wavelength of light
Psychophysical	Reception of light wavelength by the eye
Psychologic	Interpretation of light wavelength by the brain

Fig 2-16 When red, green, and blue wavelengths are mixed together, white light is created.



Color Reproduction

Color is reproduced by means of three-dimensional color models that are based on the same mechanism by which color is perceived by the human eye (referred to as *tristimulus data*) as well as the emission, reflection, or transmission of light, depending on the medium. Colors may appear to be different depending on how they are reproduced.

Tristimulus data: Properties that describe how the color of the object appears to the observer or how the color data would be reproduced on a device such as a computer monitor or printer in terms of coordinates /values.

Emissive media: RGB color model

Electronic media such as computer monitors and television sets create color by emitting wavelengths that are mixtures of red, green, and blue (RGB) light to stimulate the cones in the human eye. Such media therefore can produce a color spectrum that includes nearly all of the colors in the visible spectrum. Theoretically, if the RGB wavelengths were to be combined, white light would result (Fig 2-16). For this reason, red, green, and blue are referred to as the *additive primary colors*: From black, color is created by *adding* certain amounts of RGB wavelengths of light.

The process by which images are captured to be reproduced on emissive media (eg, the capture of images by a digital camera) is similar to the process that occurs when the human eye perceives color. A digital camera picks up tiny pixels of red, green, and blue light and blends them together in varying intensities to create different colors. With that said, it is important to note that a digital camera carries the same subjective values as the human eye and might not always be an accurate means to assess a patient's tooth shade (see chapter 5).

Reflective and transmissive media: CMY(K) color model

Media such as printed materials and photographs are considered *reflective*, and media such as slides and transparencies are considered *transmissive*, because, respectively, they are visualized through the reflection of light off of their surfaces and the transmission of light through their surfaces as previously described. Color reproduction in reflective and transmissive media is based on the color-absorbing qualities of materials such as ink or dye. These materials are formulated to absorb some wavelengths and reflect/ transmit others to create specific colors. The primary colors in these color systems are those created by the absorption of one of the RGB wavelengths and the reflection/transmission of the others. They are referred to as *cyan*, *magenta*, and *yellow* (CMY). Cyan is produced when red is absorbed and green and blue are reflected/transmitted; *magenta* is produced when green is absorbed and red and blue are reflected/ transmitted; and *yellow* is produced when blue is absorbed and red and green are reflected/transmitted. The absence (or subtraction) of these three colors would mean that no wavelengths could be absorbed and therefore all wavelengths would be reflected/transmitted, resulting in the color white. For this reason, cyan, magenta, and yellow are referred to as the *subtractive primary colors*: Color is created by *subtracting* (absorbing) certain numbers of RGB wavelengths (Fig 2-17).

Conversely, the presence of all three colors (CMY) should result in all wavelengths being absorbed and none reflected/transmitted, ie, the color black. Although this is true for CMY dyes used in photography, use of all three colors of printing ink will actually result in a muddy brown because of inherent imperfections in the ink. Therefore, black (indicated by *K* in order to differentiate it from blue [*B*]) ink is usually added to improve the appearance of darker colors and to create better shadow density, which is why *CMYK* and *four-color processing* are the terms usually associated with full-color printing[11] (Fig 2-18).

Color in Dentistry

Once the processes of color perception and reproduction are well understood, they can be applied to dentistry, specifically to shade-matching techniques. The important concepts include pigment colors (similar to the subtractive colors discussed above) and the dimensions of color that must be considered when matching shades.

Pigment colors

Pigment colors are the inherent hues of an object. Because these colors are perceived through either transmission or reflection of light, they are essentially the same as the subtractive colors used in color reproduction for reflective and transmissive media, as discussed above. In dentistry it is imperative to understand pigment colors since they are inherent in restorative materials (eg, ceramics, composites, and acrylic resins). Moreover, understanding primary, secondary, and complementary colors is critical to achieving accurate, esthetic shades (Table 2-3).

Primary colors: Red, yellow, blue

The primary pigment colors are very similar to the subtractive primaries, but they are referred to as *red*, *yellow*, and *blue*, rather than *magenta*, *yellow*, and *cyan*, respectively (Fig 2-19). Like the subtractive primaries, these are the colors that are perceived when one of the RGB wavelengths is absorbed: red is perceived when green is absorbed; yellow is perceived when blue is absorbed; and blue is perceived when red is absorbed.

Secondary colors: Orange, green, violet

The secondary colors are formed by combining two of the primary colors: red and yellow create orange; yellow and blue create green; and blue and red create violet (Fig 2-20).

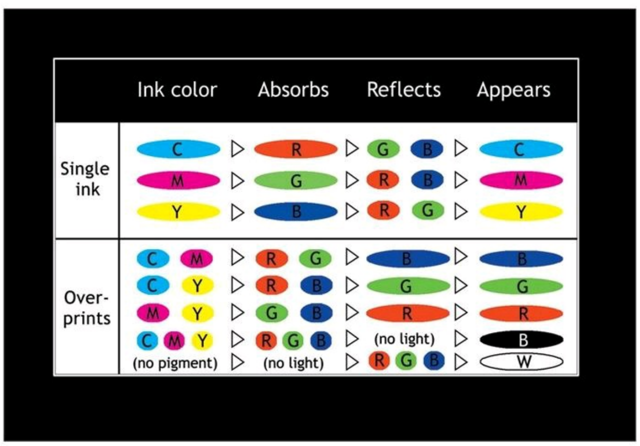


Fig 2-17 *Subtractive primary colors. Subtractive primaries are formed when one additive primary is absorbed and the remaining two are reflected. For example, cyan is formed when the additive primary color red is absorbed and the remaining two additive primary colors, green and blue, are reflected.*

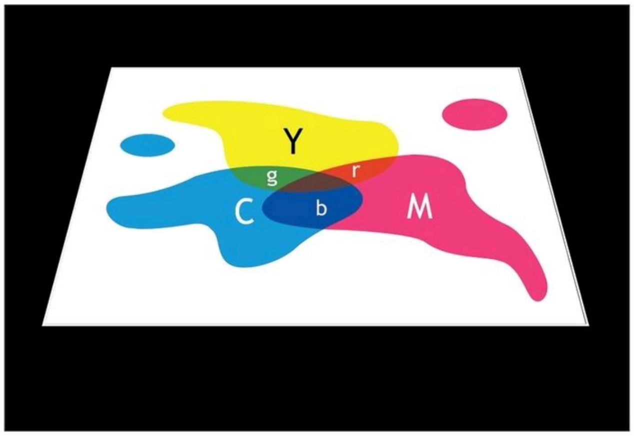


Fig 2-18 Subtractive primaries are used in color printing.

TABLE 2-3 Pigment colors

Primary color	Secondary/complementary color
Red	Green
Yellow	Violet
Blue	Orange

Fig 2-19 Pigment colors are directly related to the subtractive primary colors, but are referred to as red, yellow, and blue.

Fig 2-20 *Secondary pigment colors (orange, green, and violet) are formed when two primary pigment colors are added together.*

Fig 2-21 *Complementary colors: red/green, yellow/violet, and blue/orange.*

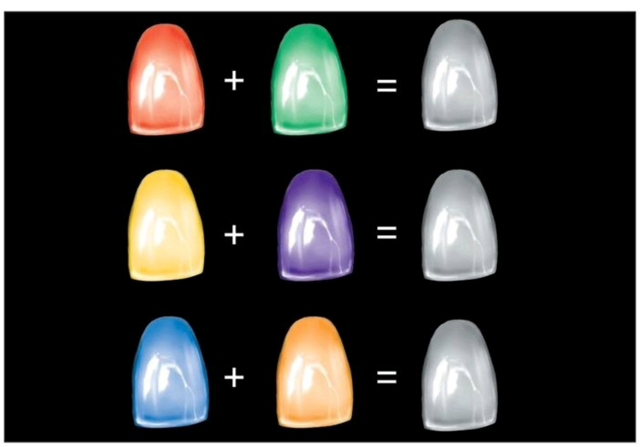


Fig 2-22 *When complementary colors are added together, they neutralize each other and form gray. This is clinically significant because complementary colors can be combined to lower the value of excessively bright restorations.*

Complementary colors

Complementary colors are so named because they "go well" together; these are the colors often seen paired in advertising (Fig 2-21). Complementary colors are those that, when combined in equal proportions, will form a dull gray that absorbs and reflects/transmits all wavelengths in equal amounts (Fig 2-22). The complementary pigment color pairs are blue/orange, red/green, and yellow/violet.

The additive principle of complementary colors may be used to alter the value of restorations. For example, if the value of a restoration needs to be lowered, the complementary color can be added to that restoration to make the shade more gray and hence lower in value (eg, shade A3 contains an orange hue; therefore, adding blue stain will create a lower value).

Dimensions of color

Like the teeth and restorations we are trying to match, color is truly multidimensional. At the beginning of the 20th century, Professor Albert H. Munsell noted that each color has a logical relationship to all other colors.[12] He brought clarity to color communication by establishing an orderly system for accurately identifying every color. This "color wheel" includes the dimensions of *hue*, *value*, and *chroma* (Figs 2-23 and 2-24; Table 2-4). To these dimensions should be added *translucency*, which is not addressed in Munsell's color analysis but is perhaps the most critical factor in the quest for an esthetic restoration. The four dimensions are defined as follows:

- Hue: Synonymous with the term *color*. Used to describe the pigments of a tooth or dental restoration (eg, red, blue, or yellow).
- Value: The relative darkness or lightness of the hue. The greater the total amount of light reflected, the higher the value. The scale of value ranges from a low of 0 for pure black to a high of 10 for pure white.
- Chroma: The intensity or saturation and purity of the color tone (hue). The more wavelengths of a particular color that are reflected (relative to all other color wavelengths), the higher the chroma of that hue (ie, the color is deeper and more pure).
- Translucency: The degree to which light is transmitted rather than absorbed or reflected. The highest translucency is transparency (ie, all light is transmitted), while the lowest is opacity (ie, all light is reflected or absorbed). The incisal edges of natural teeth are translucent, and accurate translucency determination is vital to a restoration's esthetic success (Figs 2-25 and 2-26). A mistake in translucency will greatly compromise the natural appearance of a restoration. Although there is currently no method for quantifying translucency in the clinical setting, lab technicians can use a densitometer to measure the amount of light that is transmitted through a restoration or shade tab.

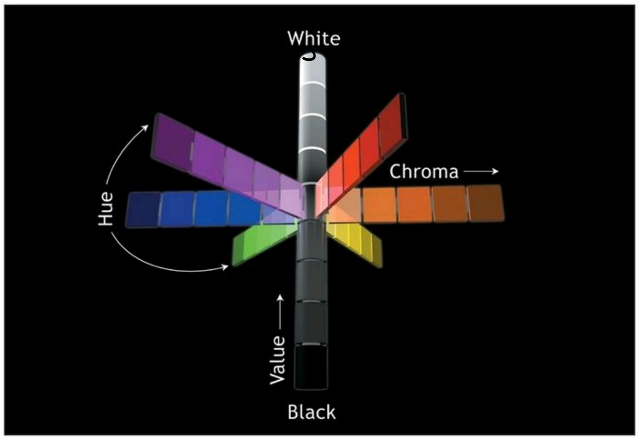


Fig 2-23 Munsell's color wheel. Color is described in terms of hue, chroma, and value.

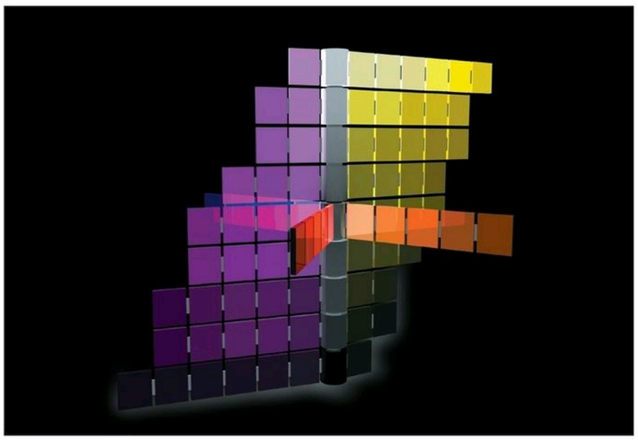


Fig 2-24 Munsell's color wheel in three dimensions. The shape of the wheel is skewed toward the red-purple colors since humans are visually more sensitive to these colors.

TABLE 2-4 Color dimension terminology

Term	Dimension of color
Hue	Color tone
Value	Relative lightness/darkness of color
Chroma	Saturation/purity of color

Fig 2-25 Maxillary central incisors with bluish incisal translucency.

Fig 2-26 Maxillary central incisors with bluish-orange incisal translucency due to aging.

Trained laboratory technicians generally can determine value and hue when presented separately. However, difficulties arise when value and chroma are coupled together, resulting in inconsistencies in value determinations for dental restorations.[13]

It is recommended that clinicians use an 18% gray card (available at most photographic supply retail outlets) as a background when viewing shade tabs and teeth to eliminate distractions in the surrounding environment and allow a more accurate determination of chroma and value (see chapter 8).

Summary

- Each individual perceives color differently.
- A full range of colors can be very closely simulated using the dominant colors: red, green, and blue.
- Control and understanding of the composition of colors is critical when attempting to alter a shade.
- Munsell defined the dimensions of color as hue, value, and chroma. However, in dentistry, translucency is of equal importance.

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CHAPTER 3 ELEMENTS AFFECTING COLOR

In this chapter:

- Illumination and clinical lighting conditions
- Contrast effects and optical illusions
- Impact of viewer's physical and mental state on color perception
- Importance of restorative material selection

Fig 3-1 Too much illumination obliterates detail necessary for accurate shade matching.

Fig 3-2 Insufficient illumination makes it difficult to discern tooth shades.

There are many variables that affect how a color is perceived. For example, the color of the ocean cannot carry a blanket description of blue. The ocean appears to be a different color at night than it does at midday, with varying hues at different levels of relative lightness and brightness. The surrounding scenery, such as the sky, beach, and vegetation, can create contrasts that affect the perceived color of the waters. Moreover, different viewers may perceive the ocean as being different colors even when viewing it under the same conditions. The same rules apply in the dental operatory during shade-matching procedures. The lighting conditions, the environment, and the viewer all play vital roles in color perception and evaluation.[1]

Illumination

Color can be neither accurately perceived nor correctly evaluated without proper illumination. It is not only crucial to have enough lighting to evaluate color properly (Figs 3-1 and 3-2), but it is also essential to achieve the proper quality of lighting. This is accomplished by using the correct light intensity and the proper illuminants. However, even when these variables are well controlled, there are certain clinical challenges associated with lighting and shade matching that must be considered.

Light intensity

The intensity of light is the most common regulator of pupil diameter, which is a crucial factor in accurate shade matching.[2] The accurate identification of color is only determined at the center of the visual field, ie, what is perceived by the fovea. The fovea is located in the center of the retina and contains a high concentration of cone cells, which provide the greatest visual acuity and most accurate color perception. Much of the rest that is perceived is “synthesized” by the visual cortex of the brain.[3] Therefore, the most accurate color reading is obtained by the human eye when the pupil is opened enough to fully expose the cones in the fovea. This is achieved by maintaining a lighting intensity of 150 to 200 foot-candles, as verified by a light meter (Fig 3-3), which facilitates accurate shade analysis and matching.

Fig 3-3 A light meter can be used to assess the proper quantity of light (150 to 200 foot-candles) in the dental operatory.

Fig 3-4 *Illuminant A represents incandescent lighting conditions with a color temperature of about 2,856 K.*

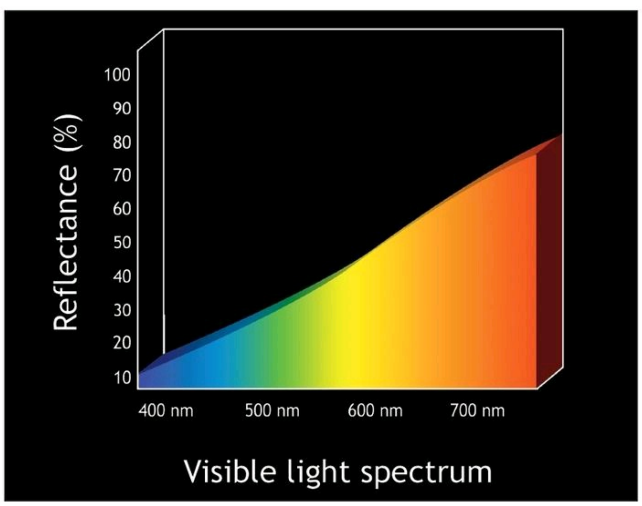


Fig 3-5 *Spectral reflectance curve for illuminant A.*

Fig 3-6 Illuminant B represents direct sunlight at about 4,874 K.

Standard illuminants

The type of illuminant used can significantly impact the perception of color. A system created in 1931 by the *Commission Internationale de l'Éclairage* (CIE; translates to International Commission on Illumination) categorized illuminants based on their effect on color perception.[4] This system was developed to allow manufacturers of products such as paints and inks to specify and communicate the colors of their products. In their report, the CIE designated three standard illuminants, A, B, and C, to which they later added a series of D illuminants, a hypothetical E illuminant, and, unofficially, a series of fluorescents (F). Following is a brief summary of the A through F illuminants[5]:

- A: A tungsten light source with a correlated temperature of about 2,856 K, producing a yellowish-red light (Figs 3-4 and 3-5). Generally used to simulate incandescent viewing conditions (eg, household light bulbs).
- B: A tungsten light source coupled with a liquid filter to simulate direct sunlight with a correlated temperature of about 4,874 K (Fig 3-6). Rarely used today.
- C: A tungsten light source coupled with a liquid filter to simulate indirect sunlight with a correlated temperature of about 6,774 K (Fig 3-7). Used in many viewing booths because indirect sunlight is considered a common viewing condition. However, illuminant C is not a perfect simulation of sunlight because it does not contain much ultraviolet light (required when evaluating fluorescence).
- D: A series of illuminants representing different daylight conditions, as measured by color temperature. Illuminants D_{50} and D_{65} (so called because their correlated color temperatures are 5,000 and 6,500 K, respectively) are commonly used as the standard illuminants for graphic arts viewing booths and correspond to bluish daylight reflectance (Fig 3-8). Illuminant D_{65} is nearly identical to illuminant C except that it is a better simulation of indirect sunlight because it includes an ultraviolet component for better evaluation of fluorescent colors.
- E: A theoretical light source with equal amounts of energy at each wavelength. This illuminant does not actually exist, but is a useful tool for color theorists.
- F: A series of fluorescent light sources. Because fluorescent lights have sharp peaks in their spectral curves and thus defy definition by color temperature, they are not officially considered

standard illuminants. However, since viewing conditions using fluorescent lighting are common, the CIE recommends certain light sources for evaluating colors destined for fluorescent environments.

Fig 3-7 *Illuminant C represents indirect sunlight at about 6,774 K.*

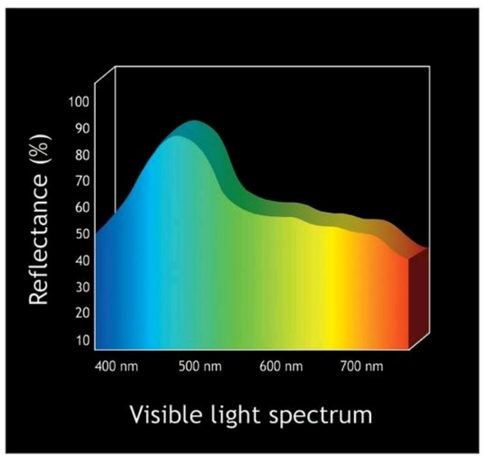


Fig 3-8 *Spectral reflectance curve for D_{50} illuminant, representing bluish daylight conditions.*

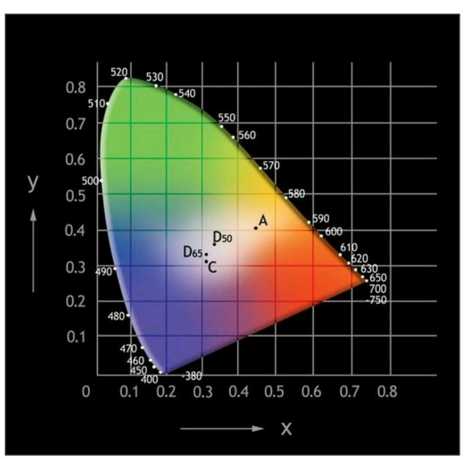


Fig 3-9 *Chromaticity diagram with plotted points representing illuminants A, C, D_{50}, and D_{65}. The*

diagram shows the distribution of color that the cones of the human eye can perceive (human eye sensitivity), based on the CIE color coordinates x and y. The cones are more sensitive to purples and reds versus yellows and greens, as demonstrated by the teardrop shape of the diagram's color distribution.

These illuminants are represented in color calculations as spectral data (Fig 3-9). The spectral reflectance power of light sources, which are emissive objects, is really no different from the spectral data of a reflective colored object. The hue, chroma, and value of different types of light sources can be recognized by examining their relative power distribution as spectral curves (Figs 3-10 to 3-13).

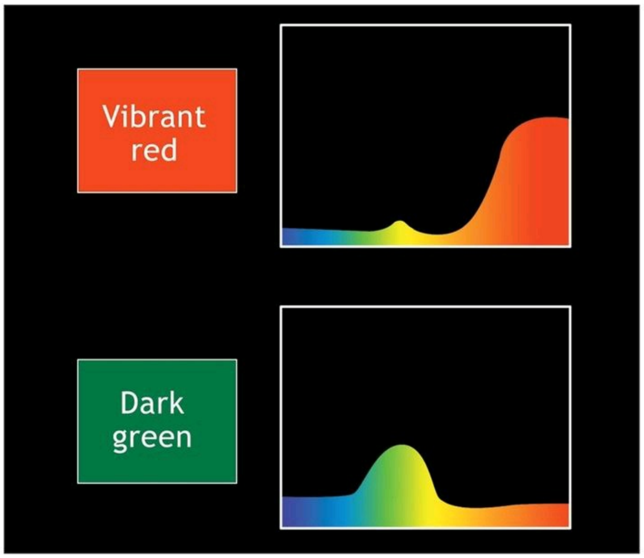


Fig 3-10 *The location of the rise of a light source's spectral reflectance curve relative to wavelength indicates its hue. Note the rise in the red wavelength for vibrant red light and the spike in the curve in the green wavelength for dark green light.*

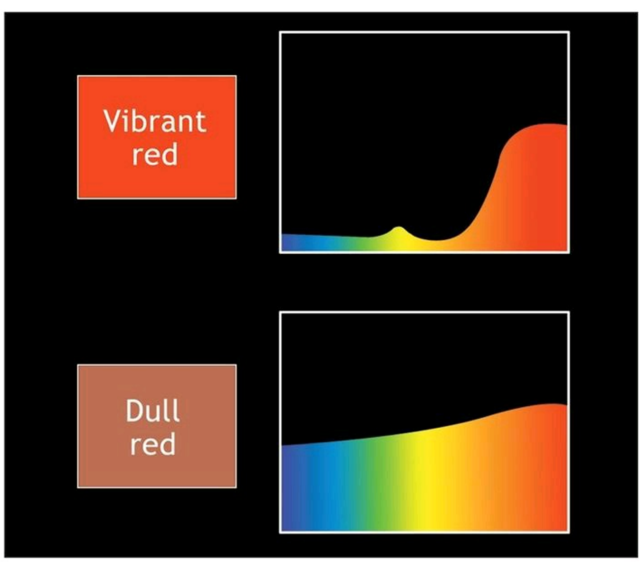


Fig 3-11 *The purity of the curve or the distinctiveness of the shape of the curve determines the saturation, or chroma, of the light. The more uniform the shape of the curve, the lower the light's*

chroma.

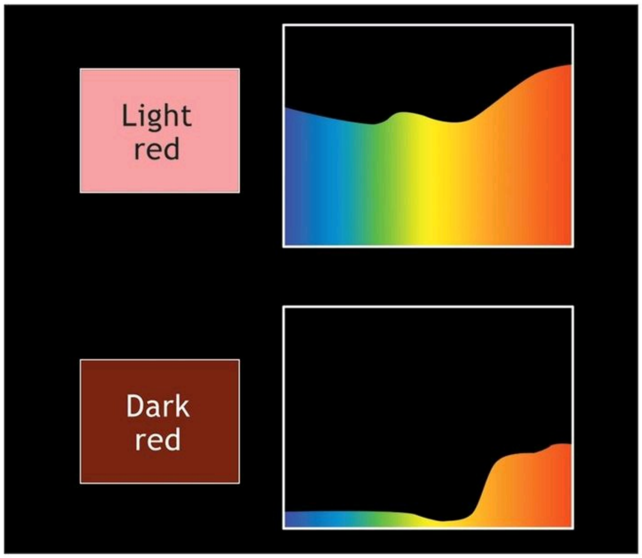


Fig 3-12 *The amplitude, or height, of the curve's waves determines the value of the light. The higher the curve, the higher the value (ie, the brighter the light).*

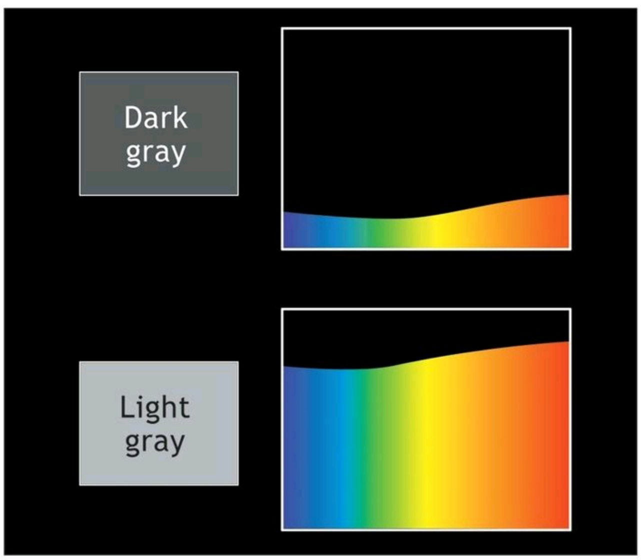


Fig 3-13 *The uniformity of these spectral curves indicates the low chroma and absence of a distinct hue that characterize gray-colored light. The difference in amplitude indicates whether the gray light is low in value (dark) or high in value (light).*

Fig 3-14 A color temperature meter, which measures lighting quality. The proper color temperature for the dental operatory is about 5,500 K.

When performing shade matching, clinicians should use D_{50} illuminants, which provide the closest lighting rendition to natural sunlight in respect to illumination *quality* and *quantity* and therefore present the best opportunity to see and select the correct shade.

Clinical lighting challenges

Dental professionals have long relied on so-called color-corrected lighting when evaluating tooth shade, yet using lights with that particular designation does not ensure accurate color matching.[2] As discussed below, the reason for this is twofold: *(1)* conflicts in lighting and *(2)* metamerism.

Lighting conflicts

The dental operatory is not free from conflicts in lighting. Light coming in through a window mixes with the fluorescent light coming from the hallway and the color-corrected lighting in the dental operatory. Amid these various lighting conflicts, it is the job of the clinician to analyze the opposing teeth and to determine an accurate shade match. The following tips[6] will aid in that process.

- If the clinician or the lab technician has access to a natural light source, it is best to perform shade matching at 10 am or 2 pm on a clear, bright day when the ideal color temperature of 5,500 K is present.
- Color-corrected lighting tubes that burn at about 5,500 K (D_{50} illuminants) should be installed when only artificial lighting is available (ie, when there is no natural light).
- A color temperature meter should be used periodically to verify that a color temperature of 5,500 K is achieved in the shade-matching area (treatment room or surgery) (Fig 3-14).
- Dust and dirt should be cleaned routinely from lighting tubes and diffusers because the presence of dust may alter the quantity and quality of emitted light.

Metamerism

Color-corrected lighting is designed to match the wavelengths and relative quantity of visible light coming from the sun; however, a person's smile will be viewed under any number of different lighting conditions, causing restorations to appear completely different in terms of hue, value, and chroma (Figs 3-15 to 3-18). Like the restorations themselves, traditional shade tabs will appear different when viewed under various lighting conditions, creating difficulties in shade matching.

Fig 3-15 *Illustration of the effect on perceived color if the proper lighting quality is not used. (a) Incandescent lighting (2,856 K). (b) Fluorescent lighting (4,000 K). (c) Color-corrected lighting (5,500 K).*

Fig 3-17 *The ceramic tooth shown in Fig 3-16 viewed under tungsten lighting (approximately 2,856 K; illuminant A).*

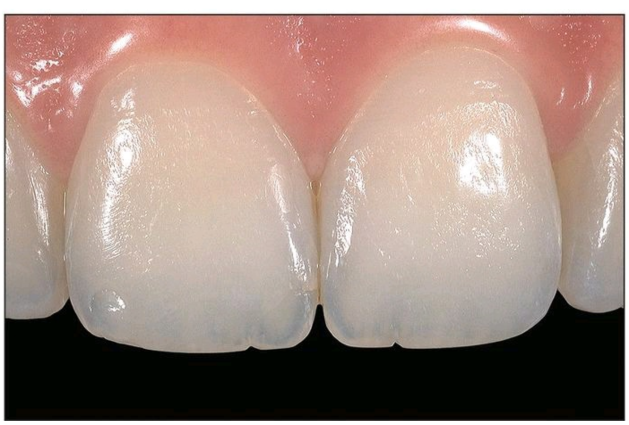


Fig 3-16 *A ceramic tooth viewed under sunny daylight conditions (approximately 5,200 to 5,500*

Fig 3-18 *The ceramic tooth shown in Figs 3-16 and 3-17 viewed under fluorescent light (approximately 4,000 K; illuminant F).*

The phenomenon of two objects appearing to match in color under one condition but showing apparent differences under another is termed *metamerism*. This is known in some circles as the “jacket and pants problem.” What can appear to be perfectly matched under the fluorescent lighting of a clothing store can look significantly different in natural light. The two objects are referred to as a *metameric pair*. In dental terms, metamerism occurs when a crown is matched to the natural dentition under incandescent light, but, when viewed under color-corrected or fluorescent light, appears not to match the natural teeth. This can occur frequently, and mistakes can often be glaring, resulting in a return visit, an unhappy patient, and unproductive chair time. However, the only sure way to avoid metamerism is to achieve a spectral curve match. Pairs of colored objects that have the same spectral curve will always match regardless of the light in which they are viewed. Advanced technology in dentistry has greatly increased the chances of achieving a spectral curve match (see chapter 5). Pairs of colored objects that do not have the same spectral components may or may not match under different lighting conditions (Figs 3-19 and 3-20).

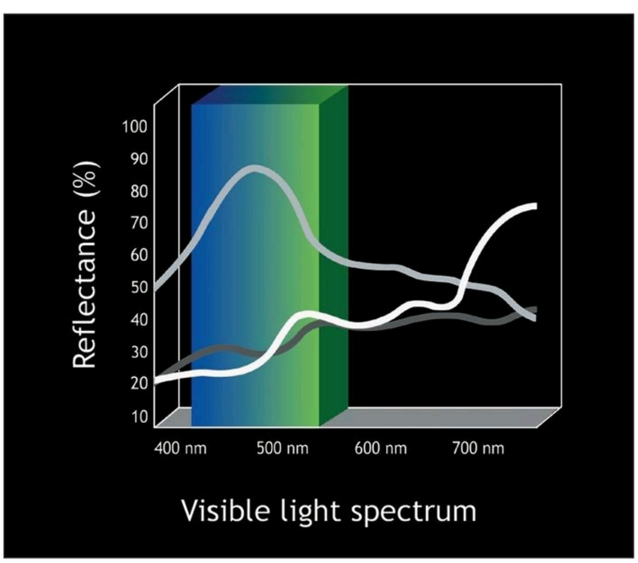


Fig 3-19 Spectral curves for light source approximating daylight conditions (gray line) and two gray objects (white and black lines). Note that the objects appear to match under these lighting conditions (the two spectral curves intersect at around 500 nm).

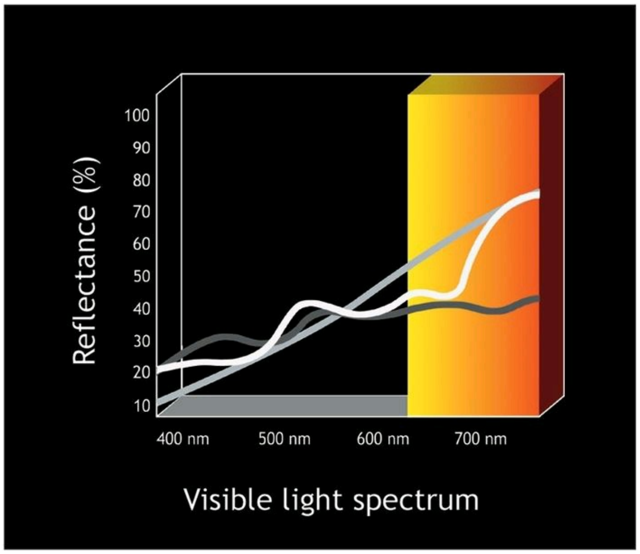


Fig 3-20 Spectral curves for warm, reddish incandescent light source (gray line) and the same two gray objects (white and black lines). Note that under these lighting conditions the two objects are no longer a visual match (ie, metamerism occurs) as the spectral curves diverge significantly at 700 nm.

Fig 3-21 Clinical appearance of a crown on the maxillary left central incisor under color-corrected lighting conditions (quantity: 175 foot-candles; quality: 5,500 K).

Fig 3-22 Same crown shown in Fig 3-21 under fluorescent lighting. Note that the crown appears to match better under this type of light versus color-corrected lighting.

Fig 3-23 Same crown shown in Figs 3-21 and 3-22 under incandescent light. The crown appears the least well matched with the surrounding dentition under this lighting.

Although some manufacturers have tried to combat metamerism by developing materials that exhibit a chameleon effect by taking on the color of their surroundings, metamerism continues to be a problem in the dental operatory (Figs 3-21 to 3-23). To combat metamerism, the clinician can perform shade selection and assessment (verification) under various lighting conditions. However, because some degree of metamerism is generally unavoidable, the clinician should explain to the patient that it is natural for the color of restorations to vary slightly under different lighting conditions and that this is an occurrence, not a fault.[7]

***TABLE 3-1* Clinical significance of contrast effects**

Contrast effect	Clinical effect	Clinical application
Value	Correlated to surrounding environment, ie, skin tone, hair color, eye color, and the value of the adjacent dentition and peri odontium. A darker environment will make a tooth appear lighter and vice versa.	Select lighter shades for patients with lighter tones and darker shades for those with deeper tones in the dentofacial area. Err toward the value tendency of the surrounding dentition (ie, low value if dentition is dark, high value if denti tion is light).
Hue	The complementary color of the surround ing background or environment is more apparent in the tooth.	Use a light blue or neutral gray (18%) back ground card when selecting shades to eliminate surrounding distractions and to precondition the eyes for improved perception of comple mentary color tones.
Chroma	A less chromatic background will make the tooth color appear more intense and vice versa. Also, a background with a hue and chroma	Use background cards with a lower chroma (eg, gray) relative to the shade of the tooth to make the tooth shades more intense and

	similar to that of the tooth will make it difficult to discern the tooth shade.	therefore easier to discern.
Areal	Large teeth appear lighter; light teeth appear larger; small teeth appear darker; dark teeth appear smaller.	If a restoration appears too large, consider decreasing the value by half a shade.
Spatial	Recessed teeth appear darker; dark teeth appear more recessed; protrusive teeth appear lighter; light teeth appear more protrusive.	Recessed teeth can be made lighter; pro truding teeth can be made darker. Consider orthodontic therapeutic correction, bleaching, or conservative esthetic restoration.
Successive	When one color is viewed immediately following another, an afterimage often will appear and affect perception of the second color.	Take breaks between looking at different shades to avoid the effects of afterimages.

Contrast Effects

Contrast effects are visual phenomena that can considerably alter the perception of color, as well as the ability to evaluate color in a clear, concise, and objective way. These effects create optical illusions that are difficult to decipher unless the observer is prepared for them. The different categories of contrast effects are described in the following text and summarized in Table 3-1.

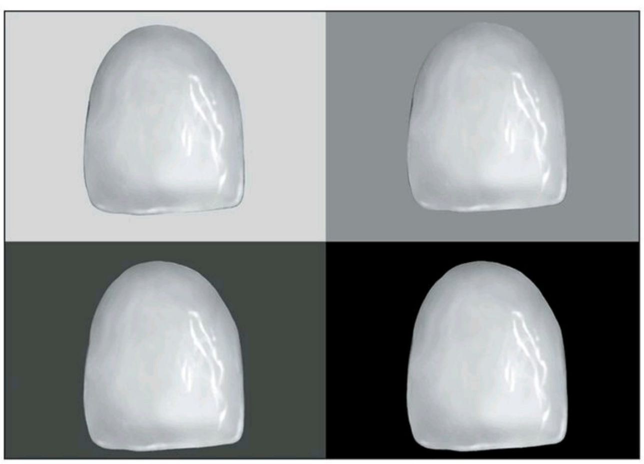


Fig 3-24 *Value contrast effect. The same tooth appears increasingly lighter as the backgrounds become darker.*

***Figs 3-25** and 3-26 A ceramic tooth appears lighter against a dark background (Fig 3-25, left) than it does against a lighter background (Fig 3-26, right).*

Simultaneous contrast

Simultaneous contrast occurs when two colors are observed at the same time. When perceiving more than one color at once, the brain will attempt to achieve a harmonic balance of the colors. Perception of the color therefore is affected by three factors: *(1)* the surrounding relative lightness (the color will appear to be darker in lighter surroundings and vice versa); *(2)* the surrounding color (the color will appear to have shifted toward its surrounding color's complement); and *(3)* the surrounding relative saturation (the color will appear to be more intense in less chromatic surroundings and vice versa). These effects are referred to as value contrast, hue contrast, and chroma contrast, respectively.[8]

Value contrast

Visual judgment of lightness is not dependable, primarily because the relative lightness of an object is affected by the lightness of the contrasting background or surroundings. For example, if the surrounding background is dark, an object will appear light. However, if the same object is placed against a lighter background, it is perceived as darker (Figs 3-24 to 3-26). What this illustrates is that the perceived lightness can vary, even though the reflectivity of the object is constant. This is due to the fact that the retina is very sensitive to light. It expands and contracts in response to varying light intensities as they are interpreted by the brain. If the background is darker than the object, the retina must adapt to the relatively lighter object, causing the brain to perceive it as lighter than if the object were viewed by itself. If the background is lighter than the object, the opposite effect results. However, because the eye adapts much more quickly from dark to light than from light to dark, the effect of a darker object on a lighter background will always be more pronounced.

Fig 3-27 Value contrast effects have clinical significance when dealing with excessively inflamed gingival tissues. The dark value of the inflamed gingiva will trick the eyes into perceiving the tooth shade as being lighter than it actually is. As a result, the fabricated restoration will appear too dark once the tissues have healed.

Fig 3-28 A common clinical scenario of excessively inflamed gingival tissues due to either periodontal disease or violation of the biologic width. To avoid errors caused by value contrast effects, shade-matching procedures should not be performed until such inflammation has been resolved.

A practical dental example of this phenomenon is when a restoration is viewed adjacent to inflamed gingival tissues (Figs 3-27 and 3-28). The redness (darkness) of the gingiva (background) distorts color perception, making the restoration (object) appear lighter than it actually is. As a result, a crown that is too low in value (ie, dark) may be chosen. The mistake becomes apparent when the tissues heal and the crown appears darker than the adjacent teeth.

To combat value contrast effects in dental restorations, relatively lighter shades should be selected for patients with light-toned surrounding dentition and soft tissues, while darker shades should be chosen for patients with darker pigmentation in the dentition and soft tissues, since teeth will appear darker in contrast with lighter tones and lighter in contrast with darker tones.

Hue contrast

A color will be perceived differently when viewed in conjunction with various background or adjacent colors with contrasting hues. When a color is viewed simultaneously with another color, the perceived hue of the first color will appear more similar to the complementary color of the second color. For example, a tooth or restoration will appear bluish against an orange background and purplish if the background is yellow (Figs 3-29 to 3-31). Using this contrast effect, dental professionals can precondition their eyes when taking shades by first looking at a complementary color, then looking at the tooth shades. This will allow the clinician to see the color of the tooth shades more effectively.

A majority of tooth shades fall into the orange hue family.[7] To view the orange tones with a more critical eye, dental professionals can precondition their eyes by looking at a light blue shade immediately prior to the shade selection process. The closer the tooth shades are to the complementary color (ie, light orange), the more vibrant they will appear.

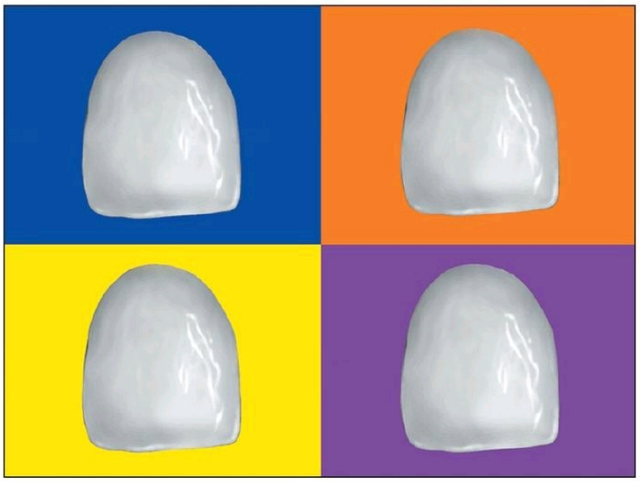


Fig 3-29 *Hue contrast effect. When viewed against different background colors, the teeth appear to take on the hue of the background's complementary color.*

Fig 3-30 *The yellow background causes the ceramic veneer restorations to take on a purple cast when viewed for a prolonged period of time.*

Fig 3-31 *The same ceramic veneers shown in Fig 3-30 appear orange in hue because of the blue background.*

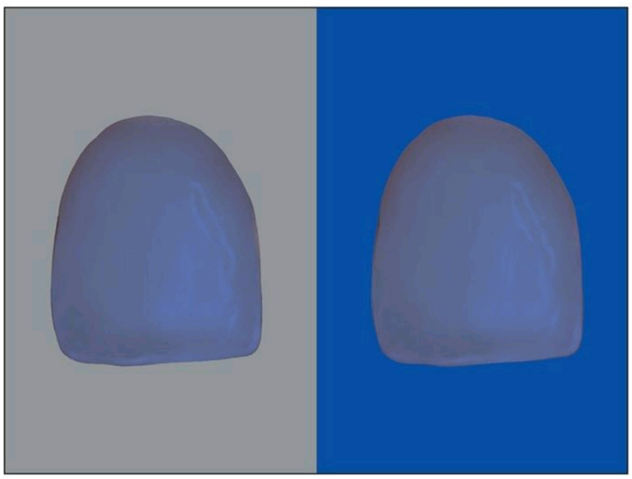


Fig 3-32 *Chroma contrast effect. The highly chromatic tooth appears more vibrant against the background that is low in chroma and less vibrant against the background that closely matches the chroma of the tooth.*

Chroma contrast

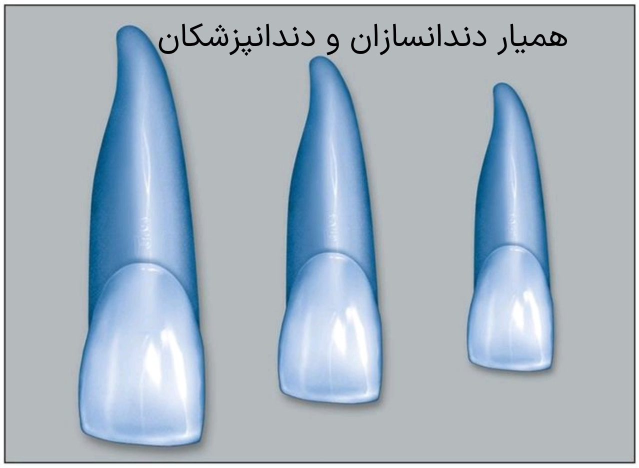
This contrast follows the same effect as the value and the hue contrasts. An object will appear more intense against a background low in chroma, and less intense against a more chromatic background (Fig 3-32). In addition, the closer the object is to the hue and chroma of the surrounding background, the less visible it becomes. This is important to remember during shade matching; using backgrounds of similar hue and chroma to the teeth will make it more difficult to distinguish the shade (Figs 3-33 to 3-35).

Fig 3-33 *A ceramic tooth without influence of background chroma effects.*

Fig 3-34 *Ceramic tooth shown in Fig 3-33 against an orange background. Note that the tooth is less visible against a background similar in chroma.*

Fig 3-35 *Ceramic tooth shown in Figs 3-33 and 3-34 against a yellow background. The tooth is even less visible against a background that very closely approximates its chroma.*

Fig 3-36 *Areal contrast effect. A larger image appears lighter since the surface area is greater and reflects more light back to the observer. Conversely, a smaller object is less reflective and appears darker.*



Areal contrast

The size of the object can also influence visual color perception. For instance, a larger object will appear lighter than a smaller object of the same color. Likewise, a lighter object will appear to be larger than a darker object of the same size (Fig 3-36). This type of contrast accounts for the fact that darker clothes have a tendency to make an individual look smaller and thinner, while lighter clothes tend to make the individual appear larger and heavier.

If teeth or restorations appear too large, consider decreasing the value (Figs 3-37 and 3-38). If they appear too small, the value may be increased by one half the shade. Teeth or restorations that appear darker than the surrounding dentition because of a smaller size may be lightened with a bleaching or whitening procedure or by replacing the restoration.

Figs 3-37 and 3-38 *Clinical case of very large maxillary central incisors as part of a fixed partial prosthesis. Even though all of the teeth are the same shade (Vita A3), the central incisors appear lighter because of areal contrast effects.*

Fig 3-39 Spatial contrast effect. Teeth that are rotated and/ or recessed relative to the adjacent teeth appear to be darker.

Fig 3-40 Clinical example of spatial contrast. The mandibular right central incisor appears darker than the other teeth because of its recessed position.

Spatial contrast

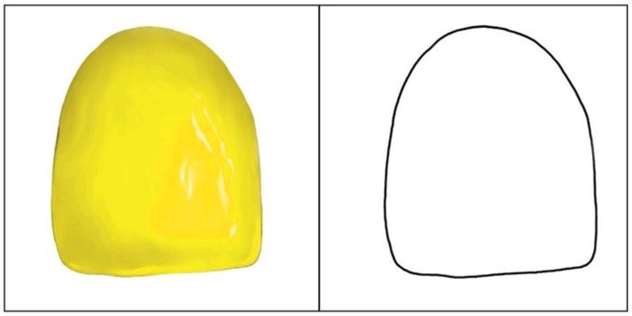
An object closer to the observer will appear larger and lighter, whereas an object more recessed will appear to be smaller in size and darker. This phenomenon is frequently seen with rotated and overlapped teeth. The recessed teeth appear to be darker (Figs 3-39 and 3-40). Posterior teeth also appear to be darker, and the shadows in the mouth further contribute to this appearance.

When determining the shade of a restoration, the clinician should maintain the same distance from the patient's mouth in order to get a consistent reading. To compensate for spatial contrast, recessed teeth can be made lighter, and protruding teeth can be made darker.

Successive contrast

Successive contrast occurs when one color is viewed following the observation of another color. The visual perception remains after the eye has left the object. Afterimages are categorized as positive (similar) or negative (different). Positive afterimages have the same color as the original perception; negative afterimages have the opposite, or complementary, color to the original perception. Positive afterimages occur following a short visual interaction, while negative afterimages occur after long visual contact with an object (Fig 3-41). The latter is caused by depletion of the neurotransmitter rodopsin in the cones of the retina during prolonged staring, which makes it physically impossible to see that particular color.

Fig 3-41 *Successive contrast effect. A positive (similar) or negative (complementary) afterimage of the colored tooth will be seen in the blank tooth after brief or long visual contact, respectively, with the colored tooth.*



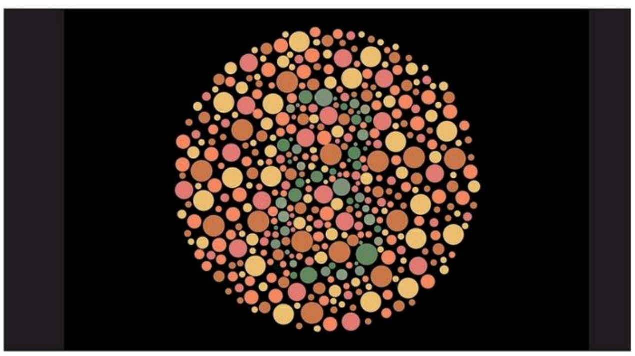


Fig 3-42 *Color blindness test to assess levels of sensitivity to green and yellow. The number 8 should be visible.*

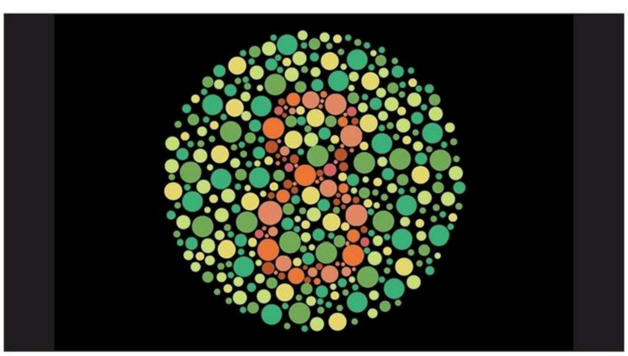


Fig 3-43 *Reversed color blindness test. The number 8 is more easily seen because its purple-red color is easily detected by the cones of the eyes.*

Understanding how color perception can potentially deviate because of various contrast effects allows the clinician to select a shade more effectively. When the clinician has a solid understanding of how opposing and adjacent colors can play tricks on the interpreter, the chances for an accurate shade match can be dramatically improved.

Viewer-Associated Effects

Color blindness

A person with color blindness has trouble seeing red, green, blue, or mixtures of these colors. The term *color vision problem* is often used instead of color blindness because most people with color blindness can see some color. Although the condition might be perceived as rare, approximately 10% of US males (but only 0.3% of US females) are affected by color blindness.[9] Most optical exams include tests for color blindness (Figs 3-42 and 3-43).

Color blindness is caused by a deficiency in or absence of one or more of the three types of photosensitive pigments able to detect red, green, and blue. These pigments are contained in the photosensitive cells in the human eye that allow color perception. These cells are called *cones* and are located in the center of the retina. The essential effect of color blindness is that hues that appear different to most people look the same to those with color blindness. In other words, having a color vision deficit means that the ability to discriminate hue, saturation, and lightness is reduced (although lightness is less affected since the rods are responsible for that part of visual color discrimination). This is a serious problem for a clinician performing shade matching since determining the hue, value, and chroma of a restoration is critical to its natural appearance.

Age

Aging is detrimental to color-matching abilities because the cornea and lens of the eye become yellowed with age, imparting a yellow-brown bias and causing the differentiation between white and yellow to become increasingly difficult. This process begins at age 30, becomes more noticeable after age 50, and has clinical significance after 60 years of age. After age 60, many people have significant difficulties in perceiving blues and purples.[10,11]

Fatigue

Tired eyes cannot perceive colors as accurately as alert eyes can. Compromised visual perception is the consequence of systemic, local, and/or mental fatigue. The inability to accurately determine hue and chroma is most evident during times of fatigue; in addition, color may be perceived as faded or blurry. Successive shade observations (ie, treating many patients requiring shade assessment during a single workday) can be one of the primary causes of fatigue. Fatigue is the most common cause of an inaccurate shade match.

When evaluating multiple consecutive shades, the dental professional should take a brief break between restorations. This will help avoid the problems associated with both successive contrast and fatigued eyes and thereby ensure greater success in achieving an accurate shade match.

Nutrition

An individual's eating habits play an important role in the health of the eye. Some scientists have suggested that there is an association between macular degeneration (a physical disturbance of the center of the retina [called the macula] causing gradual loss of vision) and a large intake of substances high in saturated fat.[12] There is also evidence that eating fresh fruits and dark green, leafy vegetables may delay or reduce the severity of macular degeneration. Additionally, supplementation with antioxidants such as vitamins C and E has been shown to have positive effects in slowing the progression of the disease in some cases. Other trace minerals and nutrients such as zinc and lutein are also important for the health of the eyes.[13] An individual's nutrition is an essential factor in the overall health of the body, and the eye is certainly no exception.

Emotions

Color can function as a language. For example, in many places throughout the world, red suggests anger or passion, yellow represents joy, and blue is associated with sadness. Without delving into the complexity of the human emotional tie to color, it is worthwhile to note the following scientific evidence, which is of significance to the dental professional.

It is generally known that emotion can affect pupillary diameter, causing dilation or constriction, and, as stated in the previous discussions about light intensity and value contrast, pupillary diameter has a direct effect on color discrimination. Additionally, it has been shown that in the practice of meditation a subject can be trained to control brain wave patterns to favor certain waves; when in meditation, people report the appearance of colored halos around objects, as well as other alterations of visual perception. It is therefore clear that regardless of how a color may affect a person's mood, the initial mood or mental state of the observer can be a critical factor in color determination.[14]

Medications

The abuse of drugs, alcohol, and caffeine will affect not only judgment, but also color perception (Table 3-2). In addition, many prescription and even over-the-counter medications are associated with visual side effects. Medications can act on any part of the visual system from the visual cortex to the retina. Like all drug side effects, they vary from person to person. Some side effects are neither predictable nor apparent to the individual taking the medication. It is safe to assume that most clinicians will take some medication in their lives, and the older people get the more likely they are to take multiple medications. Viagra, a drug used to treat erectile dysfunction, is notorious for causing vision to have a blue tint, which makes it difficult to distinguish between blue and green. As a result of these findings, the Federal Aviation Administration now requires all commercial airline pilots to refrain from the consumption of Viagra 12 hours prior to flight time.[2]

TABLE 3-2 Effect of chemicals on color perception

Drug	Effect on red/orange/yellow	Effect on blue/green/purple
Alcohol or morphine	Lighter	Darker

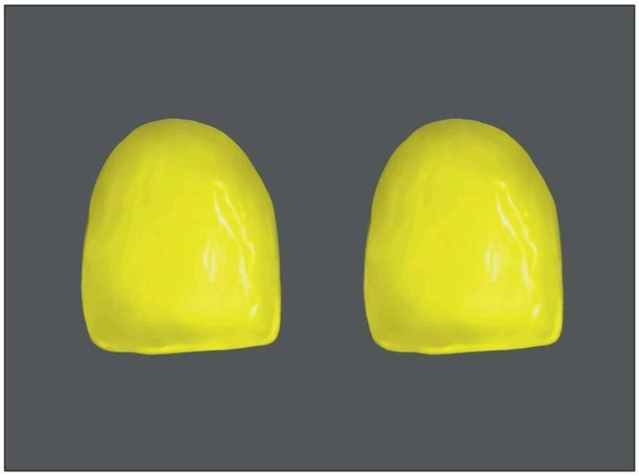


Fig 3-44 Binocular difference in color perception. When two objects of the same shape and color are arranged side by side, they may appear to be different, eg, one may seem to be slightly lighter than the other.

Fig 3-45 If the two objects are placed on the same side, the effect is not evident.

Of special concern for female practitioners are the side effects caused by oral contraceptives, ie, redgreen or yellow-blue discrimination defects. They also can cause a blue tinge, and there are several studies that indicate that long-term use of oral contraceptives will cause a decrease in color perception of blues and yellows.[15]

Binocular difference

Binocular difference is the perception difference between the right eye and the left eye. It often becomes evident during an eye exam when a person can see the vision chart better with one eye than the other. It is also not uncommon for color blindness tests to be conducted during a routine eye examination to establish the patient's deficiencies in each eye. While color disparity between a person's eyes is relatively minor, one should be aware of it and, if necessary, compensate for it. To check for binocular color difference, two objects are placed side by side under uniform illumination. They may appear different, eg, the one on the right may seem slightly lighter than the one on the left (Fig 3-44). A binocular color difference exists if the object on the right still appears lighter when the placement is altered.

Placing shade tabs either above or below (rather than next to) the tooth to be matched will help to eliminate error caused by binocular difference (Fig 3-45).

Fig 3-46 *Clinical photograph taken in natural light of two extracted teeth (center and right) and one all-ceramic tooth replica (left). Materials that allow technicians to mimic the natural appearance of human teeth are presently available.*

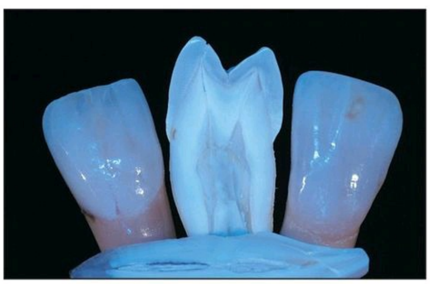


Fig 3-47 *The same teeth shown in Fig 3-46 under reflected light. The properties of the ceramic tooth are similar to those of the natural teeth.*

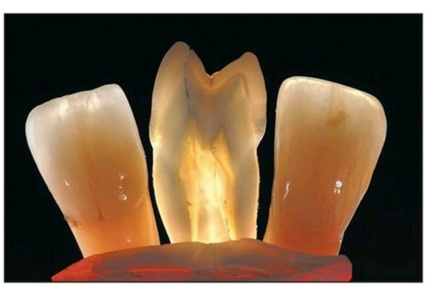


Fig 3-48 *The same teeth shown in Figs 3-46 and 3-47 under transmitted light. The ceramic tooth exhibits the same translucency as the natural teeth.*

Fig 3-49 Bleached teeth can be challenging to match because they are achromatic, ie, devoid of hue and chroma, leaving value as the only visual parameter.

Restorative Materials Selection

The choice of restorative material is extremely important for achieving an accurate shade. The relative translucency of the tooth to be matched and the material selected must coincide (Figs 3-46 to 3-48). Bleached teeth can be especially problematic to match (Fig 3-49). This is because their color is achromatic: Hue is white; chroma is low (ie, there is little saturation of hue); and value is high (ie, light). Value is the only tangible parameter that can be addressed; however, it is related to opacity/translucency. Certain materials are higher in translucency (eg, synthetic ceramics), while others are higher in opacity (eg, zirconia and alumina); therefore, identification of the material's inherent qualities is imperative when quantifying shade (Table 3-3).

It is important to note that although the correct restorative material and shade may be selected, there is still the possibility for error due to inconsistencies and variations in the materials, for which it is difficult to control.[16–22] Moreover, improperly prepared teeth, eg, preparations with incorrect reduction, may contribute to an inaccurate shade match. However, if the protocol recommended in chapter 8 is followed, mistakes resulting from these issues should be discovered in the laboratory during shade verification and corrected before the restoration is returned for clinical try-in.

TABLE 3-3 Fracture toughness and relative optical properties of materials for ceramic laminate veneer restorations

Material	Brand names	Flexural strength (MPa)	Translucency
Slip-cast alumina ceramics	In-Ceram (Vita)	630	Low
High-alumina-reinforced (sintered) ceramics	Procera (Nobel Biocare)	600	Low
Leucite-reinforced ceramics	Empress I (Ivoclar-Vivadent)	180	Moderate
	Cerpress SL (Leach & Dillon)	180	Variable
Feldspathic ceramics	Creation (Jensen Industries)	90	High
Synthetic low-fusing quartz glass-ceramics	HeraCeram (Heraeus-Kulzer)	120	High

Fig 3-50 Natural extracted teeth under natural daylight conditions.

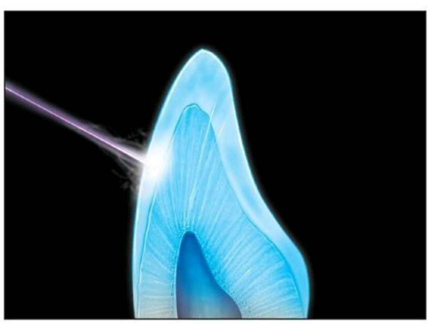


Fig 3-51 Illustration showing how ultraviolet light interacts with the cells of the dentinal layer, which emit reflected light. This phenomenon is known as fluorescence.

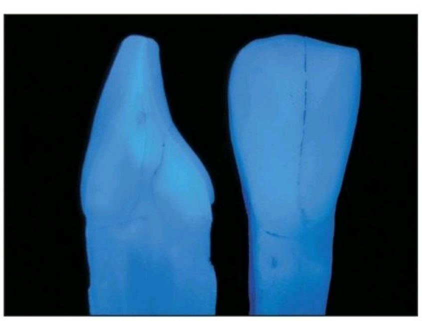


Fig 3-52 The teeth shown in Fig 3-50 under ultraviolet light. Note the greater fluorescence of the dentinal layer compared with the enamel layer.

The optical triad: Fluorescence, opalescence, and translucency

For clinicians who practice esthetic restorative dentistry, particularly in the field of ceramics, fluorescence is an important physical property. By their very nature, teeth (more specifically, dentin) are fluorescent because they emit visible light when exposed to ultraviolet light (Figs 3-50 to 3-52). Porcelain consists of agents that cause the restoration to become fluorescent. Fluorescence adds to the natural look of a restoration and minimizes the metameric effect.

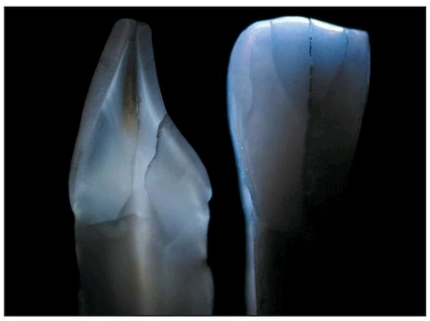


Fig 3-53 A blue opalescent effect on the teeth shown in Figs 3-50 and 3-52, caused by the reflection and transmission of blue wavelengths of light.

Fig 3-54 An orange opalescent effect on the teeth shown in Figs 3-50, 3-52, and 3-53, caused by the transmission and reflection of red-yellow (orange) wavelengths and the absorption of blue wavelengths.

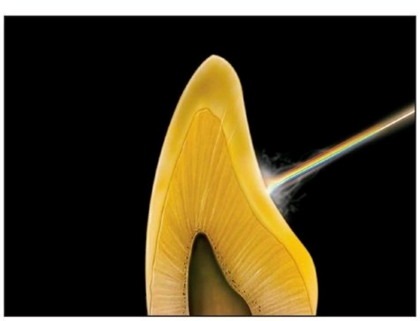


Fig 3-55 *Illustration of the transmission of the longer orange wavelengths of light through the dentinal and enamel layers.*

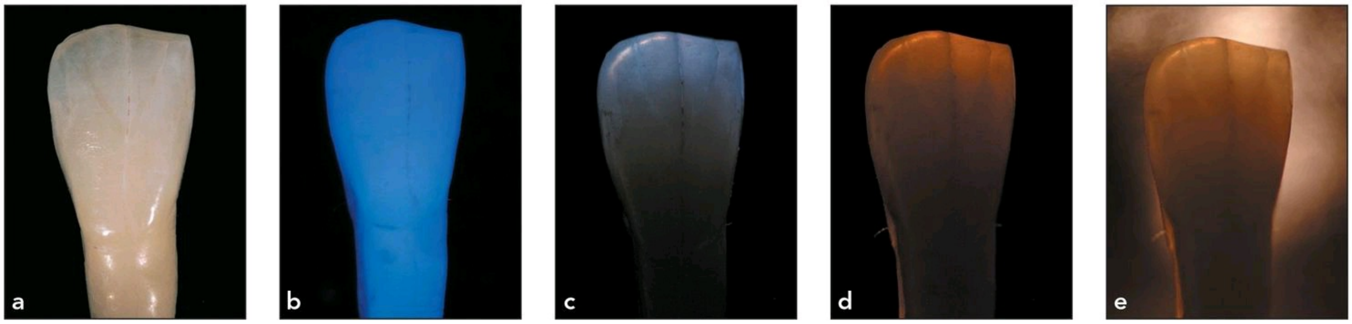


Fig 3-56 *In vitro examples of light effects exhibited by a natural tooth. Natural light effects (a), fluorescence (b), opalescence (blue [c] and orange [d]), and translucency (e) are shown.*

Opalescence is the ability of a translucent material to appear blue in reflected light and red-orange in transmitted light. The opalescent effect is based on the behavior of translucency of natural teeth. Under direct illumination, the shorter wavelengths of the visible spectrum (ie, blue wavelengths) are reflected from the fine particles of natural enamel and dental porcelain, giving the white tooth color a bluish appearance, while the longer wavelengths (ie, red-orange wavelengths) are absorbed (Fig 3-53). In transillumination, however, light penetrating through a natural tooth appears orange since the longer wavelengths are reflected at the surface and, conversely, the shorter, blue wavelengths are absorbed (Figs 3-54 and 3-55). This effect, known in optical physics as the *Tyndall effect*, is called *opalescence of natural teeth*. Both opalescence and fluorescence are responsible for the intrinsic brilliance of natural teeth that clinicians and ceramists try to imitate when fabricating artificial restorations.[23] Likewise, depth of vitality is conveyed through translucency (Fig 3-56).

It is essential to avoid excessive opacity, which results in a lifeless-looking restoration, as well as excessive translucency, which results in a restoration that looks too gray and dark.

Fig 3-57 *Fabricated ceramic teeth with a progression from shade B1 (Vitapan) (far left) to bleached shade 010 (Ivoclar) (far right). (Courtesy of J. Kim, CDT.)*

***Figs 3-58* and 3-59** *Light transillumination of B1 shade (Fig 3-58, left) and bleached shade 010 (Fig 3-59, right) shows that both shades allow the same amount of light transmission. Therefore, fabricated teeth can be white and bright while maintaining a high level of translucency. (Courtesy of J. Kim, CDT.)*

Bleaching

Most people say they want *white* teeth. However, the color white is scientifically described as being completely reflective of all visible wavelengths of light, which implies an opacity that is undesirable in the dentition. In the context of esthetic dentistry, *white* as an ideal tooth color refers to the lightness or translucency of a tooth or restoration. When teeth are bleached, the relative lightness (value) of the teeth is increased, making them appear whiter. Therefore, bleaching does not necessarily involve making the teeth more opaque and reflective; rather, intrinsic colored pigments are removed, allowing a tooth to become whiter yet remain highly translucent (Figs 3-57 to 3-59). Usually, bleaching is performed through the application of a gel containing oxidants (eg, carbamide-peroxide). Oxygen radicals released from the gel penetrate the enamel and oxidize many of the dark colorants in the dentinal layer that may be of intrinsic or extrinsic origin. The structure of teeth remains the same, while the value of the teeth increases.

Conclusions

There are several factors that can influence the dental professional’s color assessment. When using traditional shade-matching techniques, there are several variables that the dental professional should consider. For example, changes in operatory lighting, fatigued eyes, and various contrast effects can create optical illusions. Additionally, the side effects associated with the use of oral contraceptives are a problem for female practitioners, and the high incidence of color blindness among US males is of equal concern. Although no dental practitioner can read color perfectly, and no dental operatory is free from problems, a thorough understanding of the potential factors affecting color perception allows the dental professional to compensate for them as required to achieve the most accurate shade match possible.

Summary

- Lighting plays a critical role in shade matching. Color can appear different under operatory lighting than it does in natural light. The dental professional should be prepared to compensate for this phenomenon.
- Various contrast effects (value, hue, chroma, areal, spatial, and successive) can create optical illusions that interfere with accurate color evaluation. However, in some cases, effects such as

hue contrast can be used to improve color perception.

- An individual's overall health is connected to the health of the eyes, which can greatly affect the observer's color perception.
- As dental professionals age, their color perception is greatly affected.
- The selection of restorative materials plays a pivotal role in the determination of shade.

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CHAPTER 4 CONVENTIONAL SHADE MATCHING

In this chapter:

- Shade guide systems
- Shade-matching method
- Recommended shade-matching protocol

For nearly a century, dental professionals have relied on tooth shade guides for an “accurate” shade match. Shade guides are sets of physical standards that are routinely used in dentistry for visual comparison with natural teeth in order to match color and other optical properties of the target tooth or restoration. Unfortunately, this conventional form of shade taking is oversimplified; there is too much subjectivity and too little offered in terms of a legitimate standard. However, shade tabs are useful as visual guides if not as definitive answers; therefore, the conventional method does have its merits, particularly when used in conjunction with technology-based shade matching (see chapter 5). The value of this method also depends on the education and training of the clinician performing shade matching, the quality of the shade guide used, and the quality of the shade-matching method and conditions.

Shade Guide Systems

There are a variety of commercial dental shade guides available. While useful, their inherent subjectivity and other traits make them prone to inconsistencies. For example, shade guides keyed to both ceramic and resin prostheses are available, yet some of these guides are not made out of actual restorative material. This can cause several problems, such as inexact color matching and metameric behavior.

Vita Classical

In the Vita Classical shade guide, the tabs are arranged alphabetically according to hue:

- A = Orange
- B = Yellow
- C = Yellow/Gray
- D = Orange/Gray (Brown)

The chroma and value for each hue are communicated by a system of numbers:

- 1 = Least chromatic, highest value
- 4 = Most chromatic, lowest value

Vita Classical (Fig 4-1) has been the gold standard for shade matching in dentistry since it was introduced in 1956. Indeed, the majority of restorative materials, particularly composite resins, are keyed to it. However, the criticism of its empiric conception, especially regarding the arrangement of the tabs and the color distribution, persists even today.[1–6] The tabs can be arranged according to value (light to dark) in addition to hue and chroma. While this adds to the shade guide's versatility, studies have found inconsistencies as a result of using the value scale.[7]

Vita 3D-Master shade guides

There are three Vita 3D-Master shade guides: Toothguide, Linearguide, and Bleachedguide. The 3D-Master tabs are marked using a number-letter-number combination (eg, 3M2), representing value, hue, and chroma, respectively. The primary group division is based on value, as follows:

- Group 0 = 3 tabs (bleached shades, the lightest)
- Group 1 = 2 tabs
- Group 2 = 7 tabs
- Group 3 = 7 tabs
- Group 4 = 7 tabs
- Group 5 = 3 tabs (the darkest)

Fig 4-1 Vita Classical shade guides.

Fig 4-2 Toothguide Vita 3D-Master shade guide.

In groups 2, 3, and 4, tabs with differing hues are divided into 3 columns, which are communicated by letters:

- L (left) = Yellowish
- M (middle) = Middle hue
- R (right) = Reddish

Within the groups, chroma is communicated by the numbers (descending vertically) following the letter:

- 1 = Low chroma
- 2 = Medium chroma
- 3 = High chroma

The Toothguide Vita 3D-Master (Fig 4-2) is a unique departure from conventional shade guides. This product, created based on research by some of the industry's leading authorities on color,[8,9] has improved conventional shade matching by removing some of the subjectivity from shade tab–based color assessment. This method is highly logical, but it can be challenging for the dental professional with little experience in shade matching or little knowledge about the physical background of the system.

1. *Value (lightness) determination.* The user selects the value level (from 0 to 5, with 0 being the lightest [high value] and 5 being the darkest [low value]) that is closest to the value of the tooth to be matched, and then takes the medium (M) shade sample from the selected value group.
2. *Chroma determination.* The user selects the color sample from the M group with the chroma level (from 1 to 3, with 1 being the least chromatic and 3 being the most chromatic) that is closest to that of the tooth to be matched.
3. *Hue determination.* The clinician checks whether the natural tooth displays a more yellowish (L) or more reddish (R) shade than the color sample of the M group selected in the second step. Now the best-matching shade sample can be determined and the information recorded in the color communication form.

The Linearguide Vita 3D-Master (Figs 4-3 and 4-4) has the same shade tabs as the Toothguide but a different design, and shade matching is reduced to two steps.

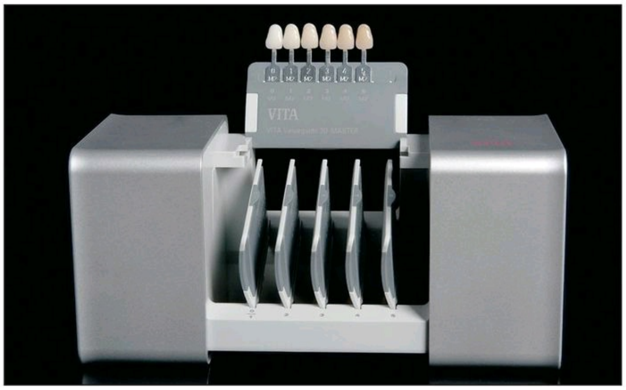


Fig 4-3 Linearguide Vita 3D-Master shade guide

Fig 4-5 Bleachedguide Vita 3D-Master shade guide.

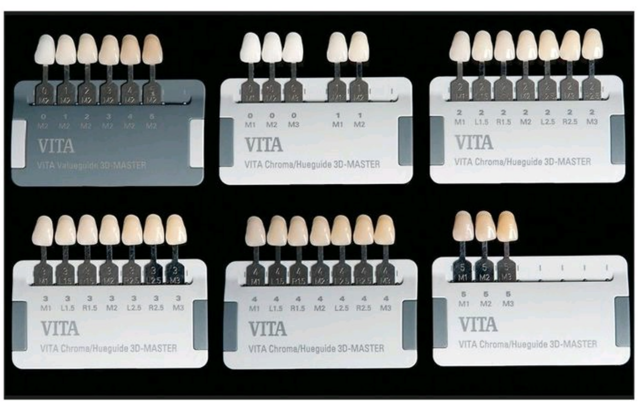


Fig 4-4 The 6 different sets of shade tabs used with the Linearguide.

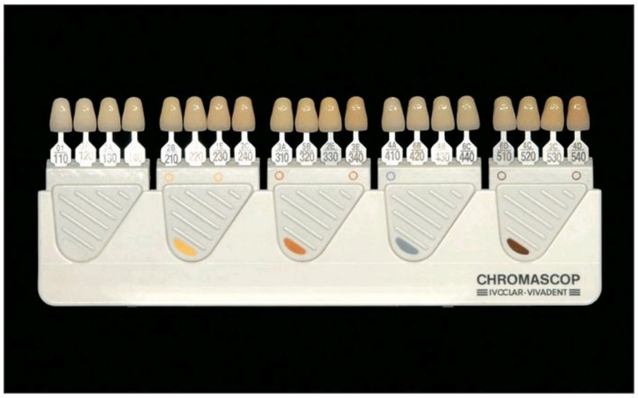


Fig 4-6 *Chromascop shade guide.*

1. *Value selection.* A dark-gray holder, containing only 6 middle tabs (0M2 to 5M2) is used. The small number of tabs with large color differences and the linear tab arrangement simplify group selection.
2. *Chroma and hue selection.* A final selection based on chroma and hue is made from the initial value group selected.

Its relative simplicity makes Linearguide recommended for a "pick the best match" approach, while Toothguide is recommended for a "dimension-by-dimension" approach. It was also found that, overall, Linearguide enables better shade-matching results and was found to be superior in a subjective evaluation compared to Toothguide. Linearguide and Toothguide were both found to enable significantly better (closer) matches compared to Classical.[10–15]

The Bleachedguide Vita 3D-Master (Fig 4-5) is the only shade guide developed specifically for visual evaluation of tooth whitening. Bleachedguide exhibits a wider color range and more consistent color distribution than the Vita Classical and other shade guides, such as Trubyte Bioform (Dentsply). In one study, the progression of lightening in natural teeth was found to be identical to the order suggested by Bleachedguide.[16–18]

Chromascop

The Chromascop system (Fig 4-6), developed by Ivoclar Vivadent, is another viable shade guide. Like the Vita Classical shade guide, the tabs are initially divided based on hue, and then further intra-group selections are made. Chromascop differs in the use of a three-digit numbering system and the use of five groups of four tabs, as follows:

- Group 100 = White
- Group 200 = Yellow
- Group 300 = Orange
- Group 400 = Gray
- Group 500 = Brown

Fig 4-7a Pretreatment clinical image of patient with "Hollywood" expectations. These patients are vocal about treatment expectations and seek a whiter, straighter appearance of their restorations.

***Fig 4-7b** Patient shown in Fig 4-7a following treatment.*

Chroma and value are communicated by a system of numbers:

- 10 = Least chromatic, highest value
- 40 = Most chromatic, lowest value

Shade-Matching Method

Analysis

Visual shade selection involves direct visual comparison of the different color samples in a shade guide with natural teeth in order to determine which tab, or combination of tabs, constitutes the best match. There are a variety of factors that can influence this determination and must be considered when employing visual shade selection.

Patient expectations

First, it is important to determine the patient's expectations for treatment during shade analysis. Generally, patient expectations fall into one of three categories:

- *Hollywood.* White and straight restorations. These patients are generally very concerned and vocal (Fig 4-7)
- *Alfred E. Newman.* Restorative design according to the clinician's expertise. The vast majority

of patients fall into this category, although most will lean toward one of the other two categories (Fig 4-8).

- *Naturalist.* Restorations that look natural and blend in completely with the rest of the dentition. These patients are often the most difficult to treat because they may have numerous craze lines, wear facets, diastemata, strange rotations, and specific contours that will have to be matched (Figs 4-9 and 4-10).

***Fig 4-8a** Pretreatment clinical image of patient with "Alfred E. Newman" expectations. These patients are easier to treat because they are more accepting of what the clinician prescribes. They can accept a straight and white or a clean and natural appearance.*

***Fig 4-9a** Pretreatment clinical image of patient with "naturalist" expectations. These patients can be the most demanding because they seek a realistic esthetic restorative effect.*

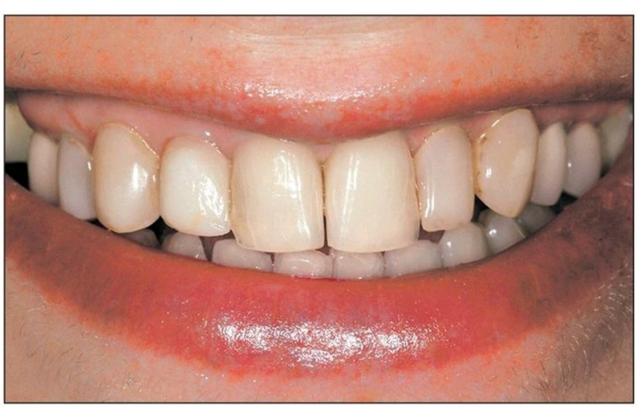


Fig 4-10a *Pretreatment clinical image of patient with "naturalist" expectations.*

Fig 4-8b *Patient shown in Fig 4-8a following treatment.*

Fig 4-9b *Patient shown in Fig 4-9a following treatment. This patient is accepting of incisal irregularities, mamelon ceramic incisal effects, and slight rotations of the maxillary incisors.*

Fig 4-10b *Patient shown in Fig 4-10a following treatment. This patient is accepting of internal characterization effects (multiple white craze lines) of the ceramic laminate veneer restorations.*

Fig 4-11 *The polychromatic effects of teeth should be noted and identified with shade tabs for each of the three distinct color zones within a tooth: gingival (G), body (B), and incisal (I).*

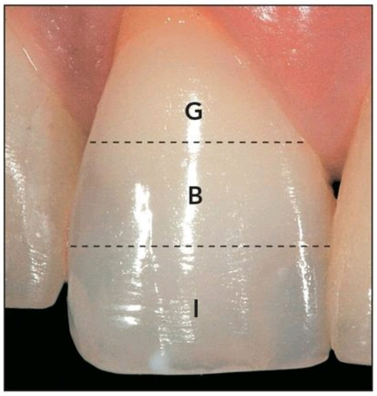


Fig 4-12 Clinical example of maxillary central incisors that are somewhat higher in opacity and lower in translucency.

Fig 4-13 Clinical example of maxillary central incisors that are relatively lower in opacity and higher in translucency.

Fig 4-14 *Clinical example of an elderly patient's maxillary central incisors with highly chromatic amber translucency. As the enamel layer becomes thinner with age, the more chromatic dentinal color shows through the tooth, creating a warm, amber color.*

Tooth anatomy

The anatomy and polymorphism of teeth uniquely influence their optical properties and thus increase the complexity of color matching in dentistry. Human teeth are polychromatic with color transitions from the gingival to the incisal/occlusal, mesial to distal, and the labial/buccal to lingual surfaces. These transitions originate from differences in thickness of enamel and dentin and, in addition to color, influence other optical properties of teeth including translucency. Because of these complexities, determining one base shade is not sufficient to obtain an esthetic shade match. The clinician must match each of three sections of the tooth: gingival, body, and incisal (Fig 4-11). One of the first steps in analysis should be to determine whether the tooth is high in opacity or translucency (Figs 4-12 and 4-13). This information will aid in the material-selection process. The clinician must also find the brightness, or value, for each section of the tooth. Next, the chroma, or saturation of tooth color, must be evaluated. An example of high chroma is the deep orange quality often found in the teeth of elderly patients (Fig 4-14).

Lighting and environment

For optimal results, shade matching should be carried out under color-corrected lighting with a color temperature of 5,500 K (D_{55}) to 6,500 K (D_{65}) and with a color-rendering index (CRI) of 90 or greater. Ideally, shades should also should be checked in natural light. The level of light intensity is also important because correct illuminance (or intensity of the incident light) can help reduce eye fatigue. Too large a difference in intensity between operatory and ambient light can provoke eye fatigue. An illuminance of 1,000 lux is considered optimal for visual color assessments.[19]

While many clinicians utilize color-corrected fluorescent ceiling lights, other types of lighting, such as floor, table, or handheld portable lamps, can also be used for shade matching. Many handheld lamps come with instructions for positioning, distance, and method. If portable lamps are used, the influence of surrounding colors is significantly reduced, especially if the ceiling light is off. Nonetheless, intense surrounding colors should be avoided in dental offices and laboratories. The same is true for strong colors on the patient's face (such as lipstick), which should be removed.

As described in chapter 3, *metamerism* is the phenomenon of two objects with different spectral properties that appear to match under one set of conditions but not under another. In dentistry, these differences are often related to hard dental tissues and restorative materials.[19] Metameric pairs are also referred to as *nonspectral* or *conditional* matches. Inversely, when two objects have identical spectral reflectances or transmittances, they can be called a *spectral*, *unconditional*, or *invariant* match. These specimens are also called *isomers*.[20] When two objects are not a spectral match, several factors can cause metamerism, including the lighting conditions, persons observing, and observation and distance angle.

Distance and position

When selecting the color for a restoration, the restoration can be a perfect match, an acceptable match, or a mismatch. Among other factors, viewing distance will impact the chances for a successful outcome. When matching a shade guide against the background of the oral cavity, adjacent teeth, gingival tissue, and surrounding skin the comparison should be performed with the clinician's eyes at tooth level, 25 to 35 cm (10 to 14 inches) away. A 1-foot distance is appropriate for color comparison of the tooth and shade tab, which should be placed in edge-to-edge contact. A neutral light gray card should be used as the background for shade matching.

When it comes to positioning, the angle of illumination and the angle of viewing relative to the surface of the tooth are important. Although different combinations are possible, the most suitable for visual color assessments in dentistry are for either the illumination or viewing angle to be 0 degrees with the other at 45 degrees or diffuse. The most common position for clinical shade selection is to view the patient, who is seated upright, at the tooth level. If the illumination is coming from the ceiling, a shadow should not be cast from the patient's nose over the shade-matching area. Shade tabs should be held next to the tooth and matched and aligned so that light reflects off the shade tab in a manner similar to that of the natural tooth.[21]

Timing and duration

The timing and duration of shade matching during an appointment will impact outcomes and should be monitored. Dehydrated teeth become lighter and need time to regain their normal coloration; therefore, shade matching should be performed at the beginning of the appointment. If needed, the teeth should be polished prior to starting to remove plaque and stains and to help keep teeth moist during shade selection. Another reason to perform shade matching early in the appointment is to avoid the potential for eye fatigue in the clinician.

The retina exhibits adaptation if an object is viewed continuously for time periods greater than 15 seconds, causing similar colorants to begin to look the same. This phenomenon necessitates glances of short duration to compare the color of a restorative sample with that of a tooth. Five-second glances with periods of rest, instead of prolonged stares, are recommended. A neutral light gray card or drape should be observed during the rest periods. Additionally, the first impression is frequently the best in shade matching because photopigment is used up quickly in the mechanism of color perception. This again suggests that shade-matching trials should be limited to 5 to 7 seconds at a time to prevent eye fatigue.

Fig 4-15 With lighter shades, hue and value are difficult to discern because chroma is so low. It is difficult to determine which shade tab is a B1 (left) and which is an A1 (right).

Fig 4-16 The conversion of shade tab information into ceramic effect powders is vital to color communication.

Tab arrangement

The method of shade matching employed will vary depending on the shade guide used. As described earlier in this chapter, the order in which tabs are selected or eliminated (based on hue, chroma, or value) depends on the design of the system. One similarity among all selection processes, however, is that the potentially appropriate shade tabs or groups can be set aside for further comparison as they are selected and unsatisfactory ones can be eliminated, thus reducing the number of choices and making the selection process easier.

Nevertheless, no method can entirely safeguard against the complexities of the psychophysiologic process that is visual shade matching. Humans cannot see hue, value, and chroma separately but can see the results of differences in these color dimensions, which occur in a wide variety of ratios.[21] An increase in chroma can be easily confused with a decrease in value: For example, although A1 of Vitapan Classical is higher in value, B1, because of its lower chroma, is considered to be the lightest shade in Classical (Fig 4-15). From that standpoint, perhaps the best approach is to select the best match without entering into the tricky combinations of the three color dimensions. If selecting dimension-by-dimension, one should pay special attention to value control. It is important because, as discussed in chapter 2, value determination directly affects the materials and type of restoration to be used, which correlate to the required tooth preparation design. Also, caution should be used when working with recently bleached teeth, which are high in value and low in chroma. A very white tooth can sometimes be the most difficult because it does not match most traditional shade guides, and bleached shade tabs are limited in their number and scope.

Communication

In the conventional shade-matching system the lab technician takes the basic information about value and chroma provided by the shade tabs and applies that information to the ceramic system and effect powders being used (Fig 4-16). Effective communication between the lab technician and the clinician is therefore critical to achieving a successful shade match. Color is a unique language spoken by the clinician and the lab technician. Acronyms abound, and a firm grasp of the language is a prerequisite to effective communication between the clinician and the lab technician. The situation is further complicated when different materials and laboratories are used.

Fig 4-17 *An aggregate in vivo photograph of shade tabs for each section of the tooth (gingival, body, and, incisal). The visual communication tool helps the technician evaluate value and chroma.*

Fig 4-18a *Reference photograph captured using a neutral flash (color temperature of 5,500 K).*

Fig 4-18b *Teeth and shade tabs shown in Fig 4-18a captured using a flash with a color temperature of 6,500 K. Note how the color of the photograph changes. This can negatively influence color interpretation by the technician.*

It is important for the clinician to discuss with the lab technician which materials will work best for a given case. Each porcelain system has its own color-matching system and nomenclature. Some laboratories and technicians may fear switching materials because of a lack of confidence not in the material, but rather in their shade-matching ability using the "color language" of a different porcelain system. It is best to partner with a laboratory that is skilled in shade matching using several varieties of materials.

It is recommended that the clinician send photographs along with the shade tabs as reference. Photography is a valuable means of communication between the clinician and the lab technician and adds credibility to the shade tab selection. Once the gingival, body, and incisal shade tabs are selected, photographs of each of the tabs should be taken next to the tooth to be matched, together with an aggregate photograph of all three tabs near the dentition (Fig 4-17). It also makes sense to photograph the matched tooth next to the two extreme shades (one lighter than the perceived shade and one darker); this allows the lab technician to get a concrete sense of the shade and value variation. Finally, photographs should be taken of the patient's face and full smile to allow the technician to envision how the restoration will fit into the patient's overall appearance.

When taking reference photographs to send to a laboratory, remember that a different flash on the camera changes the appearance of the teeth and shade tabs because of the variation in color temperature (Fig 4-18). Therefore, selecting the correct color temperature of the flash (5,500 to 6,500 K) is critical to capturing unbiased shade information in a photograph.

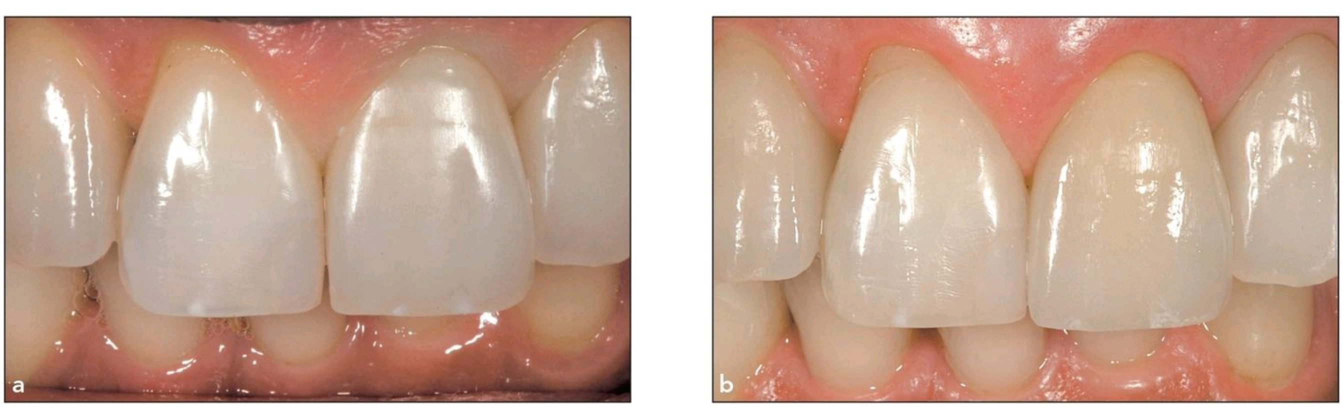
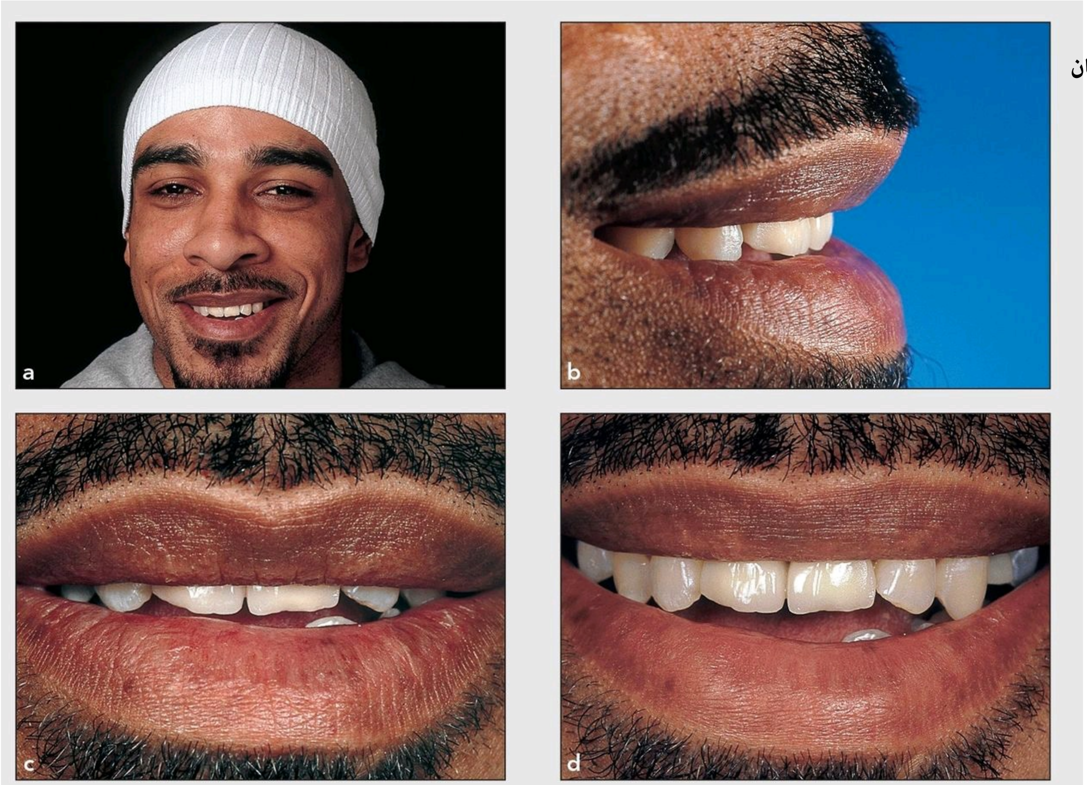


Fig 4-19 *Visual shade verification can be performed in an instant. Either the restoration matches (a) or it does not (b).*

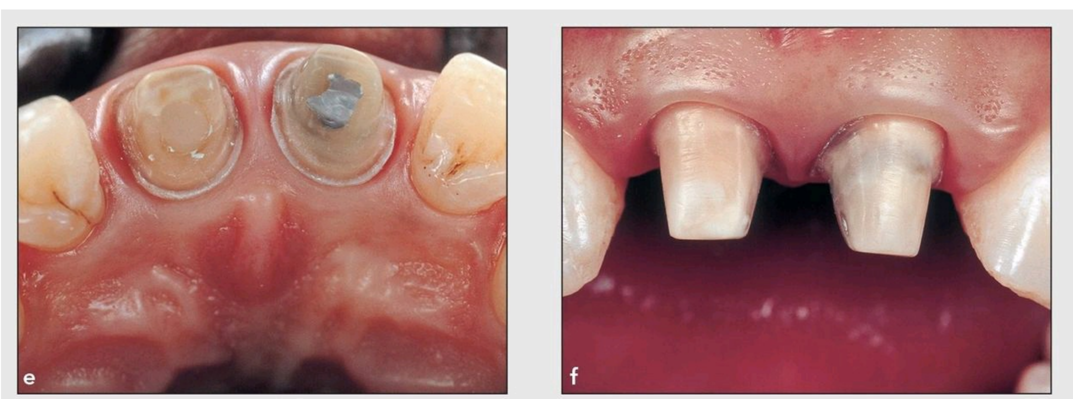
Detailed communication of color is essential to the successful delivery of esthetically pleasing restorations. In conventional shade matching, a majority of the color determination is performed visually by both the clinician and the lab technician. The subjectivity involved in assessing color is one of the most difficult barriers to accurate communication between them.[22] Once the restoration is received from the technician, the best way to verify a match is to simply look at it next to the natural dentition. It is immediately clear if the tooth shade or value is off (Fig 4-19).

Recommended Protocol

1. The patient removes any lipstick or other makeup that could affect shade matching. If the patient is wearing bright clothing, it is prudent to cover the patient with a neutral-colored bib (Figs 4-20a to 4-20d).
2. The existing tooth structure on which the restoration will be fabricated is cleaned and evaluated (eg, to determine whether it is vital or discolored by previous endodontic work or metal restorations). This will influence tooth preparation design and material selection (Figs 4-20e and 4-20f).
3. The translucency and opacity of the patient's natural teeth are determined. This will help in the material selection process (Figs 4-20g to 4-20i). Surface roughness, gloss, and local color characteristics should also be noted.
4. The shade selection is made at the beginning of the appointment, before the eyes become too fatigued. The eyes should be aligned evenly with the patient's teeth level, at a distance of 25 to 35 cm. It is important not to view the comparison for more than 5 to 7 seconds at a time to avoid fatiguing the cones of the retina. A neutral gray card should be observed between trials.
5. Shade tabs should be held and aligned so that light reflects off the shade tab and the natural teeth in a similar manner. It is important to determine the shade when the teeth are most hydrated—teeth dry out during the preparation and impression-making procedures.
6. A variety of shade tabs are used to analyze the opposing dentition's value in the gingival, body, and incisal areas. Value is analyzed first, followed by chroma, then hue (Figs 4-20j and 4-20k).
7. The number of potentially matching tabs should be reduced to a few as quickly as possible, and only these tabs should be used to complete the shade matching.
8. Final shade selection can be verified using different lights, observation angles, and distances; during different appointments; and/or by different clinicians.



Figs 4-20a* to *4-20d *Preoperative clinical photo series. All surrounding distractions that could negatively affect shade matching and communication have been removed.*



Figs 4-20e* and *4-20f *The maxillary central incisors are both nonvital; however, the left central incisor presents with greater discoloration as well as a non-tooth-colored core restoration (amalgam). This will impact the technical fabrication of the restorations if an all-ceramic material is chosen.*

Figs 4-20g to 4-20i The relative translucency of the teeth to be matched is determined. Different views and evaluation of different teeth are helpful in assessing this parameter.

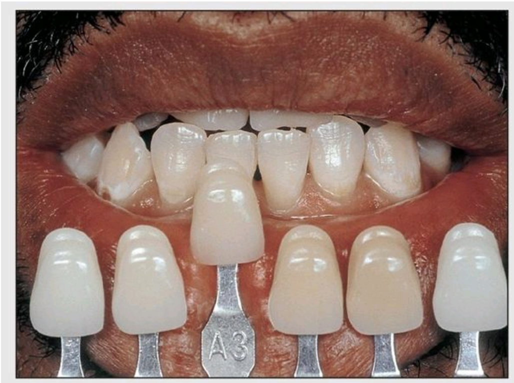


Fig 4-20j The Vita Classical shade guide is used to select the shade of the teeth in the opposing arch.

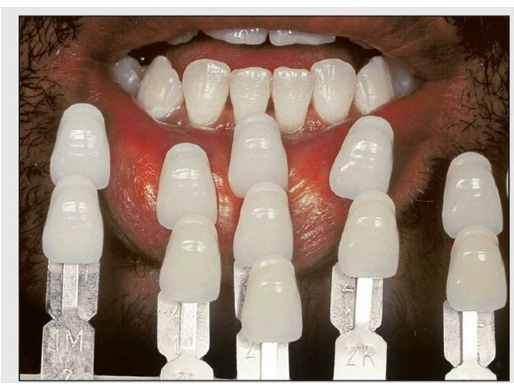


Fig 4-20k The Vitapan 3D-Master is used as a comparative analysis of shade. Using a variety of different shade guides is helpful for accurate and comprehensive shade determination.

Fig 4-20l Reference photograph of extreme shade tabs (light and dark) for value determination.

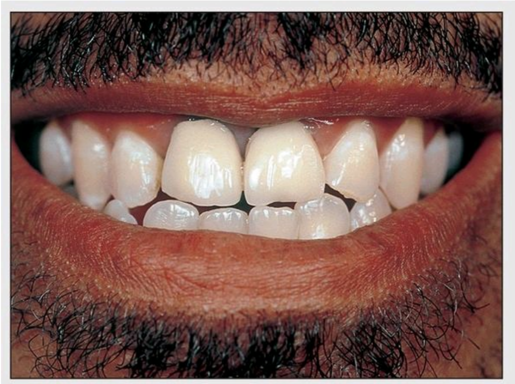


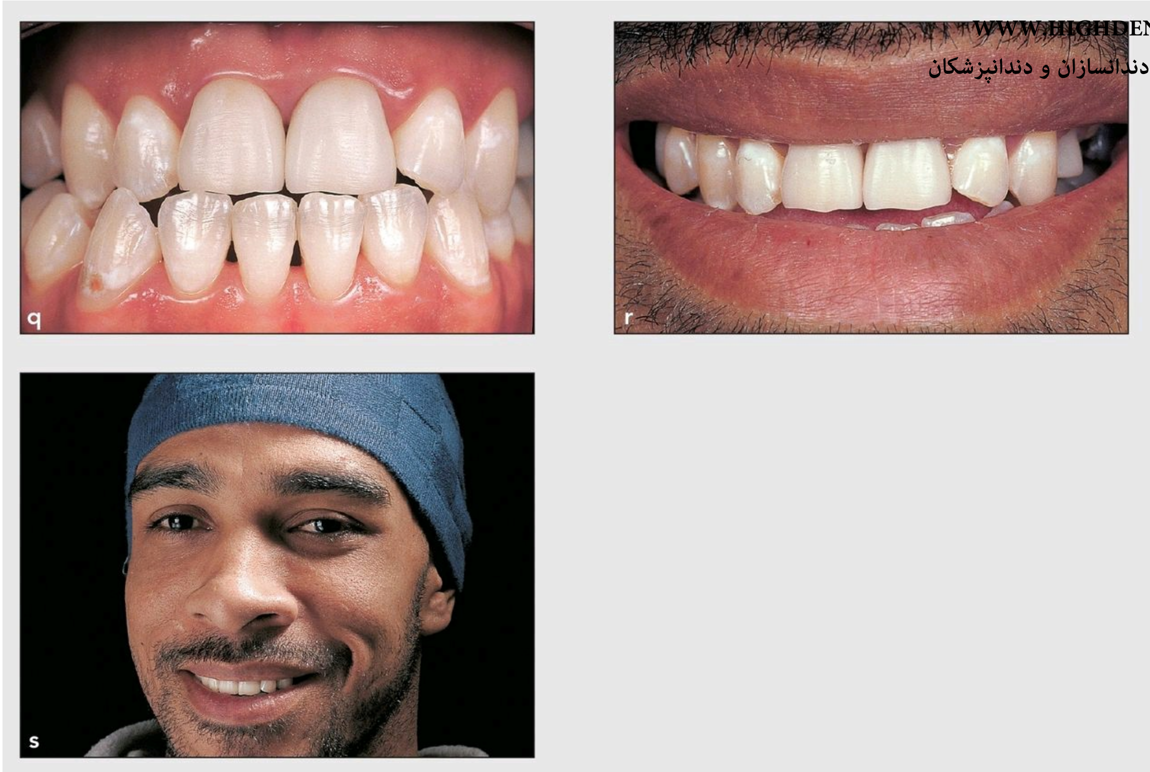
Fig 4-20m A photograph of the full smile.

9. Once an ideal match has been selected, a very bright shade tab and a very dark shade tab are photographed next to the teeth to be matched (Fig 4-20l).
10. The full smile is photographed (Fig 4-20m).
11. The clinician communicates with the technician and verifies the restoration upon receipt. This verification should be performed under several lighting conditions (eg, color-corrected light and natural daylight) to ensure the accuracy of the match (Figs 4-20n to 4-20s).

Fig 4-20n The first crowns fabricated were too opaque.

Fig 4-20o The second set of crowns was too dark.

Fig 4-20p A clinically acceptable match was achieved with the third and definitive set of crowns.



Figs 4-20q to 4-20s *Postoperative clinical photographs showing the definitive restorations in place.*

Conclusions

When tooth shade is selected using the visual method, the knowledge and skill of the practitioner is extremely important. With such a high degree of subjectivity comes significant variability in shade assessment. The development of restorative materials with improved physical and optical properties increases the need for improved methods of shade selection through new and user-friendly shade guides. Finally, didactic and hands-on media also need to be further developed to better educate and train dental professionals in color matching.

Summary

- Conventional methods are the most common approach to shade matching; however, they involve a degree of subjectivity, which can lead to unsuccessful shade matches and reduced productivity.
- The traditional shade guides that are currently available use a variety methods for quantifying shade. “Select the best match” or value-chroma-hue (dimension-by-dimension) shade-matching techniques are recommended.
- Conventional shade-matching findings should be transferred to the lab technician in sufficient detail, including reference photographs.

Acknowledgments

Figures 4-20a to 4-20s courtesy of Irfan Ahmad, BDS, Middlesex, UK.

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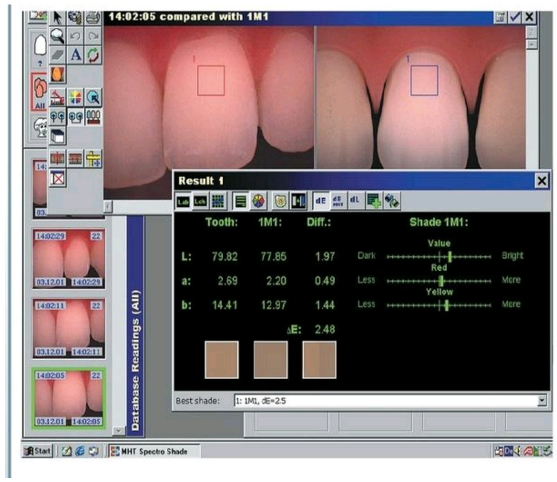
CHAPTER 5 TECHNOLOGY-BASED SHADE MATCHING



In this chapter:

- Development of technology-based shade systems
- Basic measurement systems
- Types of technology-based shade systems
- Interpretation methods of different technologies
- Shade-matching process
- Technology-based shade-matching protocol

New technology-based systems have been developed and brought to market to combat the subjectivity inherent in conventional methods of shade taking in the dental operatory. This chapter provides an overview of the current market and strategies available for successful integration of new technology-based solutions.

Precise color communication is integral to the development of esthetic harmony and overall restorative success. While traditional shade-taking procedures enable some degree of shade information transfer, contemporary shade-analysis devices allow for standardized, repeatable shade determinations by placing technology in the role of "observer" in the light-object-observer triad required for color perception (see chapter 2).

Several clinical studies have confirmed that computer-assisted shade analysis is more accurate and more consistent compared with human shade assessment.[1] The need for improvement in the accuracy of shade matching was highlighted by a study that showed that 80% of patients notice a difference in the shade of their natural teeth compared with their restored teeth.[2] Such a widespread lack of accuracy should not be accepted as the standard; rather, clinicians should strive to improve the esthetic quality of restorative work.

Advantages of computer-aided shade determination include:

- No influence of surroundings
- No influence of lighting
- Results are reproducible
- Easy documentation
- Reliable data transmission

Development of Technology-Based Shade Systems

Advances in technology in the areas of computers, the Internet, and communication systems have greatly influenced and shaped modern society. Commensurate with these strides are the advances in contemporary dentistry: During the past half decade, the dental profession has experienced the growth of a new generation of technologies devoted to the analysis, communication, and verification of shade.

Shade determination for direct and indirect restorations has always posed a challenge for the esthetic restorative dentist because color is an abstract science. The earliest color-measuring device designed specifically for clinical dental use was a filter colorimeter. The Chromascan (Sterngold) was introduced in the early 1980s but enjoyed limited success because of its poor design and accuracy.[3,4] Further development was hindered primarily by a lack of resources and commitment on industry's side—the market was too small. In the late 1980s and early 1990s, Seghi and Ishigawa-Nagai published experimental research using both colorimeters and spectrophotometers.[5–7] Several prominent color science experts also tried to objectively quantify color. Bergen experimented with spectrophotometers and computers in an effort to standardize analysis in the profession.[8] Miller used a single-point-source spectrophotometer in his research for correlating the shades of extracted natural teeth to those of available shade guide tabs.[9] Goldstein, Yamamoto, and van der Burgt all subsequently published articles on the subject.[10–12] Preston made a major contribution to the field by identifying the quantity and quality of lighting required to analyze shade properly and pointing out inconsistencies in the manufacturing of shade guides and tabs.[13] Yamamoto was instrumental in the development of the Shofu ShadeEye Chroma Meter and subsequently the Shofu NCC (Natural Color Concept) System.[14]

In the late 1990s, a company called Cortex Machina was established in Montreal, Canada, marking the birth of a new industry in dentistry—commercially available technology-based shade guide systems. Cortex Machina, a company devoted to artificial vision technologies and founded by a group of highly trained experts from McGill and Cornell universities, was approached by a dental technician, Denis Robert, who explained the problems encountered in shade taking and communication between dentist and technician. This was the first effort toward a complete analysis system that registers shade over the *entire* tooth surface. Chu and Tarnow[15] reported the clinical use and application of the Cortex Machina prototype, which employed RGB digital camera technology that inferred color properties. The authors found that the more accurate data provided by technology-based systems allowed technicians at all levels of skill and experience to produce well-matched restorations. Cortex Machina has subsequently merged with another Canadian company, Cynovad, which specializes in computer-aided design/computer-assisted manufacturing (CAD/CAM) technologies. In 2001 and 2002, the first two *measurement* analysis systems mapping the whole surface of the tooth were developed: the SpectroShade System (a spectrophotometer) from MHT (Fig

5-1) and the ShadeVision system (a colorimeter) from X-Rite (Fig 5-2). Recently, the development and integration of light-emitting diode (LED) technology into various dental fields has allowed for more portable, battery-powered devices. This development has also lowered the cost of shade analysis systems, making them more readily available.

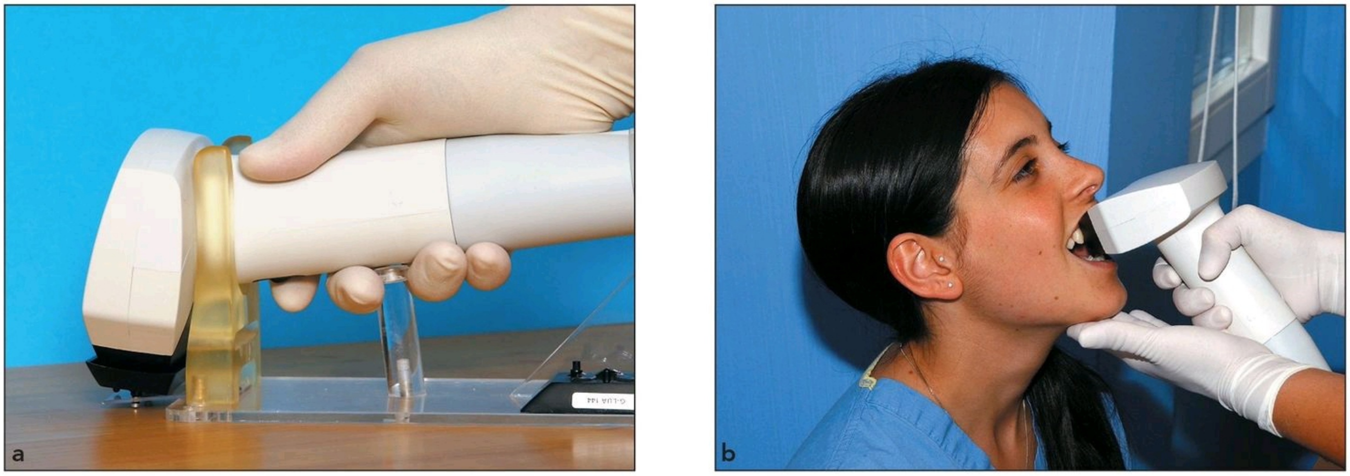


Fig 5-1 ***(a and b)*** *The SpectroShade System was the second commercially available system that maps the whole tooth surface.*

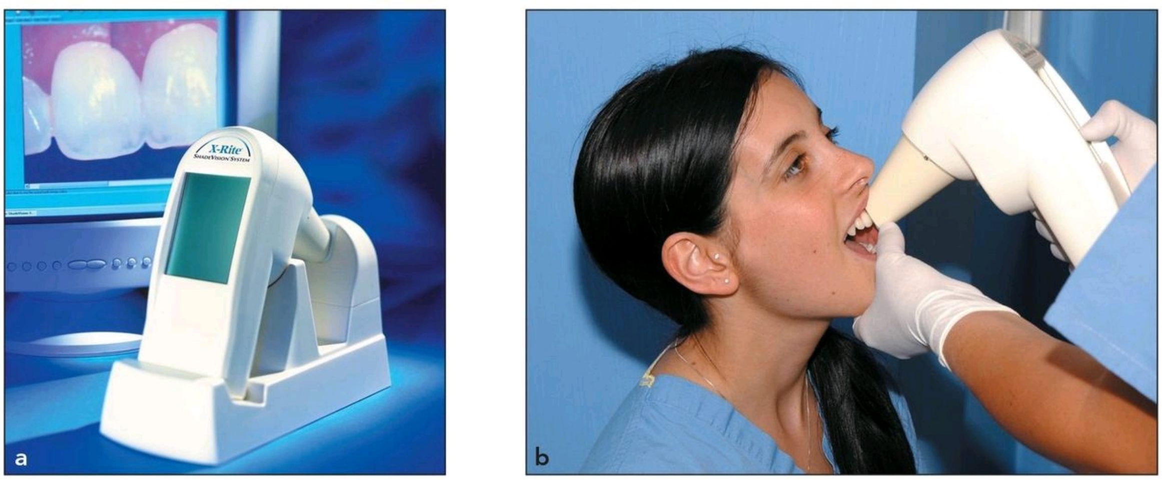


Fig 5-2 ***(a and b)*** *X-Rite's ShadeVision stores hue, value, and chroma to efficiently measure tooth shade. Its optical capture device is small, light, and easily maneuverable, allowing image capture in areas beyond the anterior dentition.*

Today's shade-matching technologies have been developed to improve communication between the lab technician and the dentist and ultimately the esthetic restorative work of the practice. These innovations mimic the human visual system without the negative visual illusion effects and deliver exact and reproducible information for the lab technician to use in interpreting and fabricating the restoration. Additionally, digital shade-taking devices are used not only to transfer a tooth shade for a restoration but also to record a treatment outcome, such as before and after bleaching results (see chapter 8).

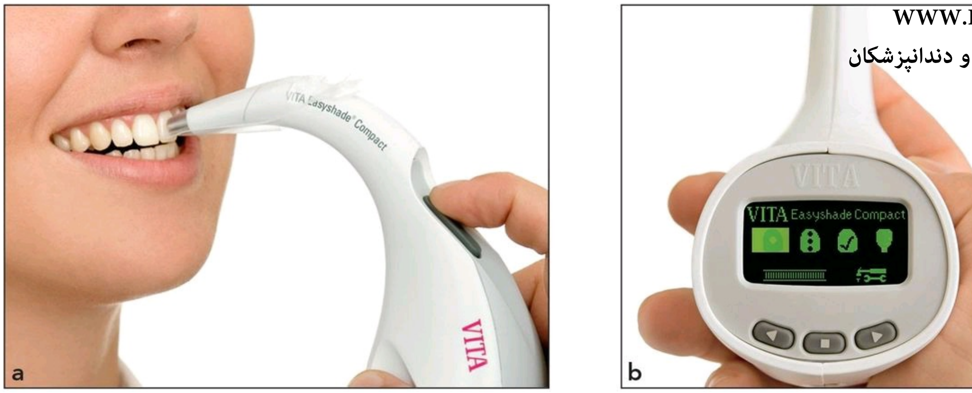


Fig 5-3 ***(a and b)*** *The EasyShade compact (a spot-measurement device). The tip of the instrument is positioned on the tooth surface. Single or multiple points can be measured on natural teeth, ceramic restorations, and shade tabs. Correct positioning of the tip is crucial for correct results.*

Basic Measurement Systems

The shade of a tooth is influenced by many factors. A shade map of a single natural tooth will reveal a large number of different shades. Translucency and opacity (see chapter 3) also play an important role in shade determination. The surface texture of the tooth has a significant impact on the visual appearance as well. In order to provide the lab technician with valuable information, it is necessary to have an overall image of the unrestored tooth, including the surrounding tissues. All color-measuring devices consist of a detector, signal conditioner, and software that processes the signal in a manner that makes the data usable in the dental operatory or laboratory. Because of the complex relationship between these elements, accurate colorimetric analysis is not easy.

Spot versus complete-tooth measurement

Spot measurement devices measure a small area on the tooth surface. The size or diameter of the optical device aperture (generally 3 mm^2) determines how much of the tooth surface and subsequent shade is measured. The average central incisor is 80 to 100 mm^2 (Fig 5-3); therefore, spot measurement cannot deliver all of the information necessary to create an overall image. Spot measurement devices generally require three points of reference each for the gingival, body, and incisal areas of the tooth (a total of nine reference measurements). This increased number equates to greater sources of error during image capture as well as increased time for shade information data capture. Moreover, the amount of data created by a spot measurement device is inadequate because of the nonhomogeneous shade structure of the human tooth. Spot measurement devices are best suited for showing shade trends or tendencies and as adjunct tools in the shade-matching process. Examples of spot measurement devices are the Vident EasyShade Compact system and the X-Rite Shade-X.

Complete-tooth measurement systems measure the whole tooth surface area and provide a topographic color map of the tooth (Fig 5-4). With a complete-surface measurement device, all of the information is captured in one image. The measurement of the complete surface gives the operator more consistent and reproducible information of the tooth structure,[1] which can then be transmitted to the laboratory. A drawback of complete-tooth measurement systems, however, is that their use is limited to anterior teeth because of the size of the sensor, which does not allow access to the molar region. Examples of these devices are the MHT SpectroShade Micro, X-Rite ShadeVision, and the Olympus CrystalEye.[16,17]

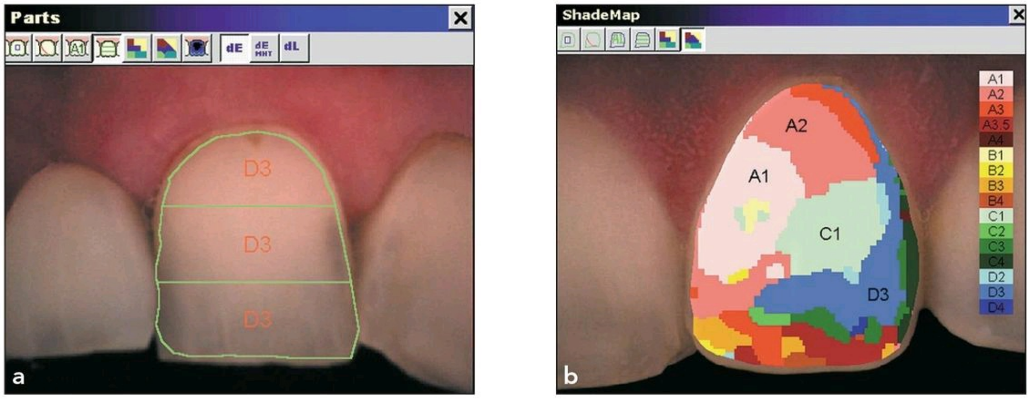


Fig 5-4 ***(a and b)*** *Complete-tooth measurement devices measure the entire surface of the tooth and provide a detailed color distribution map.*

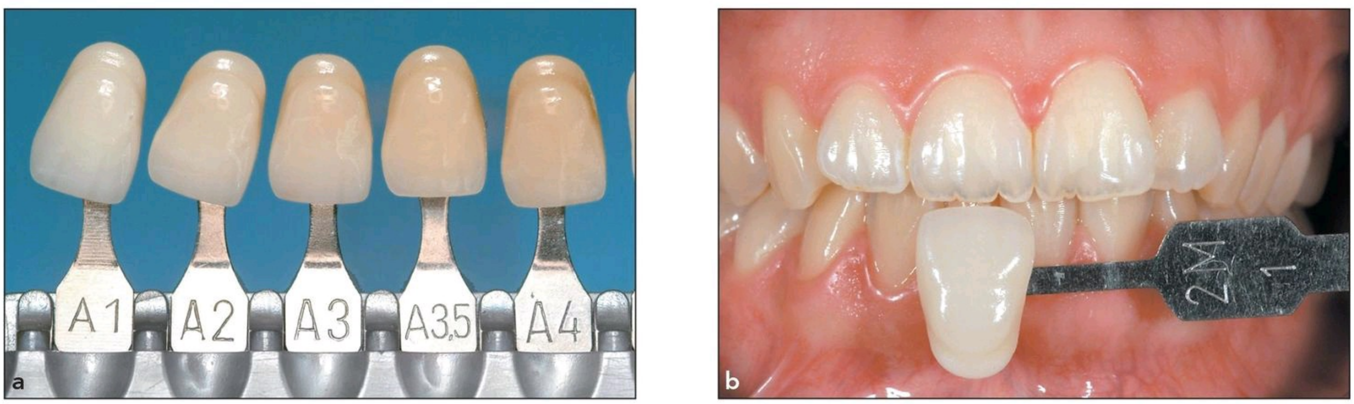


Fig 5-5 ***(a and b)*** *Traditional shade tabs should be used primarily as reference tools when technological solutions are available.*

Types of Technology-Based Shade Systems

RGB devices

Most consumer video or digital still cameras acquire red, green, and blue image information that is utilized to create a color image and are commonly referred to as *RGB* devices. Digital cameras and other RGB devices represent the most basic approach to electronic shade taking and require a certain degree of subjective shade verification with the human eye.[1] These systems are essentially still image comparison systems. Digital reference photography is used primarily to enhance communication between the dentist and the lab technician when working with traditional shade tabs (Fig 5-5).

Various approaches to the translation of this data into useful dental color information have been used.[18] The problem inherent in the use of these systems is that they do not control some of the key variables associated with accurate color determination. Typically, color is synthesized from RGB data according to various assumptions about the camera and the use of reference materials within the captured image. The information accuracy (reliability) of RGB devices is questionable since they are not measurement instruments; rather, they *infer* color properties of the captured image. These systems are more helpful for providing lab technicians with a starting reference point than for visually determining the shade of a tooth. The ShadeVision system from X-Rite is an example of an RGB device (see Fig 5-2).

Fig 5-6 *Digital cameras are useful for taking reference photographs, which are critically important for shade analysis and shade communication.*

Fig 5-7 *Reference photography is an important part of choosing the correct shade in tricky situations. For example, teeth that are high in opacity (a) are generally perceived as whiter, and the surface texture of teeth (b) can also affect their perceived color.*

Digital cameras

Though not used extensively in dentistry, digital photography and digital imaging are gaining popularity at an extraordinary rate throughout the world. At present, the use of digital photography in dentistry has no set nomenclature, procedure codes, standards, or continuity.

Digital photography, like many of the newer electronic technologies in the industry, offers significant benefits to dental practices. The digital camera is extremely efficient and easy to use; however, the practitioner needs a basic understanding of computer technology and standard photography to maximize its capabilities (Fig 5-6). Training the proper staff members to acquire and manipulate the images can make the process cost effective and beneficial for both the practice and the patient.[19] Digital photography can be an ideal adjunctive tool for the dentist and lab technician to quantify shade; however, the use of a digital camera alone is not effective for shade analysis. A shade-matching protocol using digital cameras, a gray card, and Adobe Photoshop has been described in the literature but is not yet feasible for everyday practice [20] (Fig 5-7).

Spectrophotometers

Spectrophotometers are highly precise and accurate instruments that are relatively simple and easy to use. They measure light wavelengths reflected from an object at many points along the visual spectrum (approximately every 10 nanometers), and these measurements produce spectral color data (see chapter 3, Fig 3-9) A spectrophotometer measures and records the amount of visible radiant energy for each value, chroma, and hue present in the entire visible spectrum.[1,2,21–24] These measurements result in a complex data set of reflectance values, which are visually interpreted in the form of a spectral curve (see chapter 2, Fig 2-9). Spectrophotometers measure the reflectance or transmittance factors of an object one wavelength at a time, and they have been used to measure the spectral curves of porcelains and extracted teeth. These instruments typically divide and measure the visual spectrum into multiple parts, resulting in 16 to 32 data points across that range. The extensive data obtained from spectrophotometers must be manipulated, and a data reduction strategy employed, to translate the data into a useful form (eg, a spectral curve)[25] (Fig 5-8).

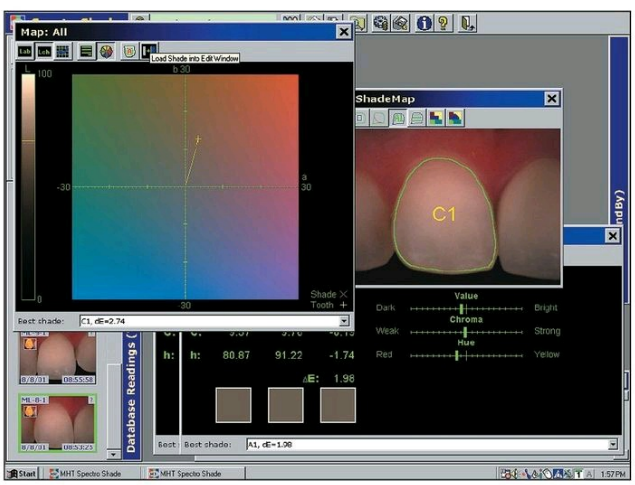


Fig 5-8 *Data obtained from spectrophotometers are often difficult to translate into everyday dentistry. However, scientific parameters and data output by such devices are highly useful in the research arena.*

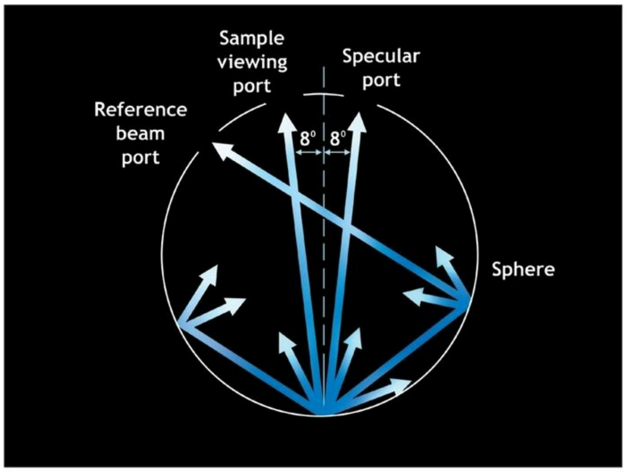


Fig 5-9 *Effective laboratory research-based spectrophotometers use spherical optics technology. This 360-degree light exposure is not achievable for dental purposes.*

Widespread use of spectrophotometers in dental research and clinical settings has been hindered by the high cost and complexity of the equipment, and, until recently, the difficulty of using the machines to measure the color of teeth in vivo.

The best research spectrophotometer uses what is called spherical optics, which allows an object to be placed inside the spectrophotometer and exposed to light from many different angles and directions (Fig 5-9). This gives the most accurate and precise spectral analysis of the reflectance properties of the object. However, for clinical dental practice, a tooth cannot be placed inside the device. Instead, light is directed at the surface of the tooth.

There are two basic optical light geometries that are used in reflectance spectrophotometer instruments: *(1)* illumination at 0 degrees and observation at 45 degrees (0/45), and *(2)* illumination at 45 degrees and observation at 0 degrees (45/0) Because of the limited access afforded by the oral cavity, only the 45/0 option is suitable for clinical use (Fig 5-10).

One example of a spectrophotometer developed for clinical use is the SpectroShade (MHT), which uses dual digital cameras linked through optic fibers to measure the color of the tooth. There is a multimodal dual-light mechanism to illuminate the tooth and allow readings of its translucency and refl ectivity.[26] The SpectroShade has the capability of displaying shade results in advanced color graphic form (see Fig 5-8). Olympus has also recently entered the market of technology-based systems with CrystalEye, a system similar to MHT's SpectroShade Micro.

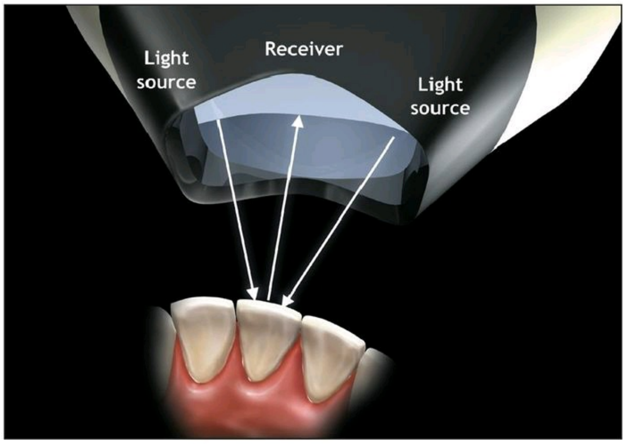


Fig 5-10 The 45/0 option (illumination at 45 degrees and observation at 0 degrees) is best suited for clinical use of spectrophotometers.

Colorimeters

Much of the dental research on the color of natural teeth and porcelains, both in vivo and in vitro, has been conducted with the use of colorimeters.[27–31] These instruments approximate the spectral function of the standard observer's eye and are engineered to directly measure color as perceived by the human eye. A colorimeter filters light in three or four areas of the visible spectrum to determine the color of an object. Colorimeters are difficult to design, and, if made improperly, will result in reduced accuracy compared with a spectrophotometer. Properly designed colorimeters such as X-Rite's ShadeVision system can provide greater data efficiency because they store only the necessary 3 data points of hue, value, and chroma instead of the 16 or more data points of reflectance.[1] A colorimeter can deliver color information accuracy similar to that of spectrophotometers and reduce the data load time by avoiding the unnecessary color mapping associated with spectrophotometers.

The ShadeVision system provides simple, reliable shade measurement information for precise, quantifi - able communications between the dental office and laboratory. The assurance of an accurate shade match is significantly improved compared with traditional techniques.

Interpretation Methods of Different Technologies

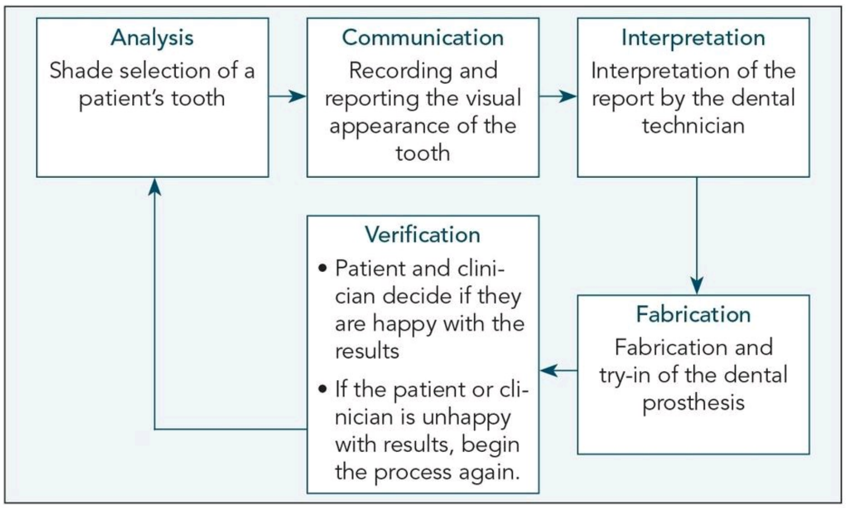
As discussed previously, the surface of the tooth has significant impact on the perceived value of the shade. The smoother (more reflective) the surface is, the brighter the surface will appear. To overcome this problem, some systems use filters to adjust for the surface gloss. Shade-matching systems that do not use such filters often record shades at a value that is too high, which can be very problematic.

Accuracy of color measurement is also affected by the phenomenon of edge loss, which occurs because of light lost primarily through the translucent tooth and ceramic enamel layers. Although algorithms are incorporated into the software to accommodate for the different light-scattering properties of teeth, crowns, and shade tabs, it is difficult to fully compensate for these differences, and this can be a significant source of error.

Translucency mapping is inadequate in all of the systems. Replication of tooth translucency remains the most challenging aspect of matching the appearance of a natural tooth. The transfer of this three-dimensional quality to a two-dimensional map provides little benefit. Systems that incorporate digital imaging have the best chance because a high-quality visual is the best that is currently available.

Positioning of the probe or mouthpiece seems to be critical to the repeatability of the measurement. In addition, any device that uses a small-diameter contact probe is limited because it cannot give detailed mapping of color on the surface and provides only a general base shade of the limited area measured. The larger mouthpieces are limited to measurements of anterior teeth because of access.[32]

Fig 5-11 Steps of the shade-matching cycle.



Shade-Matching Process

The shade-matching process (Fig 5-11) includes:

- Analysis
- Communication
- Interpretation
- Fabrication
- Verification

Analysis

Most technology-based shade systems use the ΔE* from the *Commission Internationale de l'Éclairage* (CIE) L*a*b* color system to determine the color difference between a tooth to be matched and a chosen shade. The ΔE* is a crucial element in establishing the difference between a tooth and the reference and is determined by the following equation:

$$\Delta E^*_{ab} = [(\Delta L^{*2}) + (\Delta a^{*2}) + (\Delta b^{*2})]^{1/2}$$

where L*, a*, and b* are the colorimetric data of the lightness, chroma, and hue, respectively. The resulting ΔE* is the shortest distance between point a* and point b*. The CIE (explained in chapter 3) utilized this mathematical equation to determine the final color of an object. The ΔL, Δa, and Δb, as well as the total ΔE*, are shown graphically with the ShadeVision and ShadeEye systems and in a numeric form with the SpectroShade System. Additionally, the SpectroShade allows the dental professional to change the selected shade according to different ΔE*s and allows the lab technician to approach the shade selection with a further level of detail (Fig 5-12).

In digital shade analysis, the goal is to achieve the smallest and most accurate ΔE* value possible for the gingival, body, and incisal sections of the tooth. It is important to note that ΔE* values are non-directional, ie, they do not indicate whether one shade is darker or lighter than another. The ΔL (value) is the most sig-nifi cant parameter because the human eye can detect changes in value more readily than it can perceive changes in hue. A ΔL value of less than 2.0 and a total of ΔE* of less than 4.0 have been shown to represent clinically acceptable color matching.[1] Digital shade analysis is much less time consuming and subjective than the conventional approach. The shade is taken electronically with either a colorimeter or spectrophotometer, and a color map is created automatically, verified visually, and then sent to the lab technician.

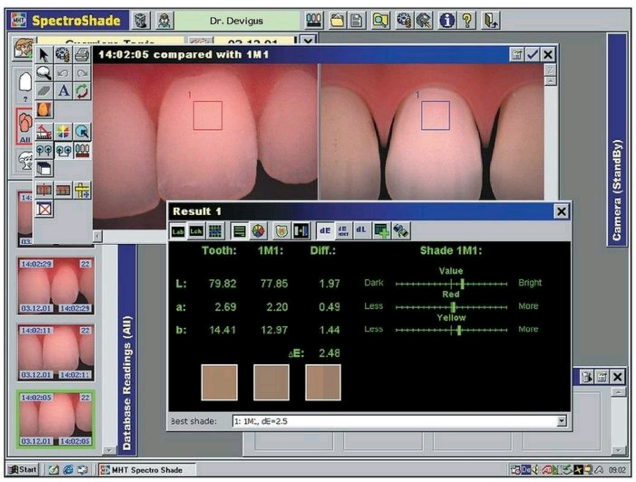


Fig 5-12 The ΔE value obtained with the SpectroShade system provides quantification of the shade difference between a selected shade and the shade to be matched. The smallest ΔE* is ideal since it implies the closest match. The ShadeVision system is also capable of providing such ΔE* data through a special software program called ShadeMatch.*

Communication

A high level of communication between the clinician and the lab technician is the basis for predictable results and a successful clinical case. There are two major components to clinician-laboratory communication:

- Administrative communication, eg, payment arrangement, remake policies, delivery schedules, and fees
- Technical communication, eg, study models, diagnostic wax-ups, occlusal records, shade tabs,

computerized shade mapping, and photographs

This text focuses on technical communication, although good administrative communication is also important to a good working relationship with a laboratory. With technology-based systems, communication is significantly improved and streamlined primarily as a result of the standardized shade-analysis reports, which allow communication to be carried out electronically. With the ShadeVision System and SpectroShade System, for example, the images are conveniently captured and the data is uploaded to the clinician's personal computer for processing. This information is easily communicated electronically or via mail to the laboratory, which then has objective data to fabricate and verify the restoration's esthetics. Even though technology-based systems capture a significant amount of detail and shade information, reference photography should be sent with the color data so the lab technician has the complete information to fabricate the restoration accurately.

Interpretation

The lab technician analyzes the color map and interprets the reference photographs before fabricating the restoration. Interpretation of the reports is still subjective, and depending upon the knowledge and skill of the lab technician, the reading can be varied. Additionally, several factors can modify the perceived color, including surface texture, anatomical form, surface gloss, marginal integrity, and fluorescence.

Fabrication

When fabricating the restoration, the technician must consider the intrinsic properties of the selected restorative material (eg, metal-ceramic vs all-ceramic), not only to match the shade but also to achieve the appropriate translucency and opacity. Extrapolated or inferred translucency maps can be interpreted to determine the ideal amount of translucency or opacity. Each tooth presents different levels of translucency, and the restorative material should reflect that.

***Figs 5-13* and 5-14** *When attempting to create a natural-looking restoration, it is important to note that tooth structure varies and changes with age. Figure 5-13 (left) presents the square-shaped morphology characteristic of adolescents' teeth, while Fig 5-14 (right) shows the more tapered and triangular shape of an older patient's teeth.*

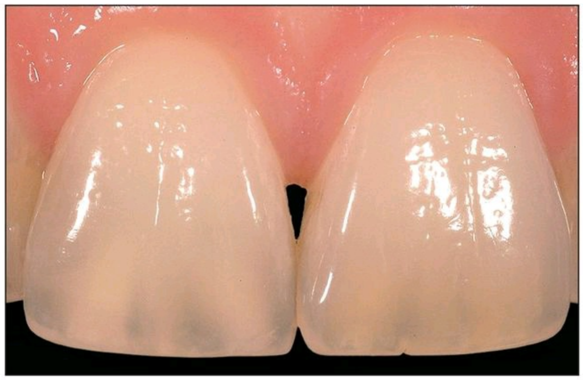


Fig 5-15 *In older teeth, dentinal structures (eg, the mam-melon structure) are more prominent because of an increased translucency of the enamel, which is caused by abrasion.*

Fig 5-16 *Calcification of the teeth leads to higher opacity with age.*

It is also important to fabricate restorations (especially ceramic ones) with shape and color that appropriately reflect the patient's age. In the oral environment, extrinsic factors, such as changes in the supporting periodontal tissues and wear facets, affect the overall tooth appearance.

In adolescents, the morphology of the visible tooth is commonly square (Fig 5-13). As people age, dentin becomes more exposed and there is wear on the incisal edge, causing the tooth to become more tapered and triangular (Fig 5-14).

In addition, in adolescence the surface characteristics are accentuated and the surface appears rough. As teeth age, their surface texture becomes more shiny and smooth because of continuous abrasion and attrition.

Aging also affects the color of teeth in the following ways:

- The dentin becomes more visible through the thinner enamel (Fig 5-15).
- Calcification increases over the years, resulting in higher translucency of the enamel[33] (Fig 5-16).
- Diffusion of light through dentin decreases with age, changing the color from an opaque light color to a translucent dark color (Fig 5-17).
- The high-value whitish color of a young patient's teeth changes to a low-value orange, then to a low-value brownish color with age (Fig 5-18).

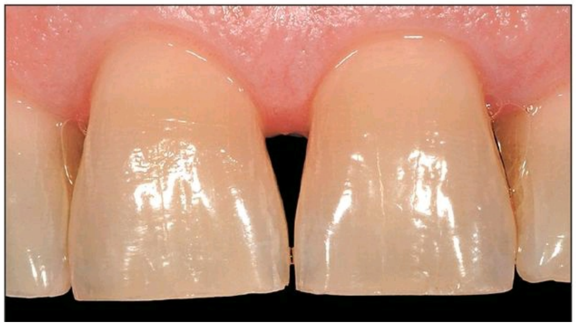


Fig 5-17 *Diffusion of light through dentin decreases with age.*

Fig 5-18 *Teeth change to a low-value orange, then to a low-value brownish color with age.*

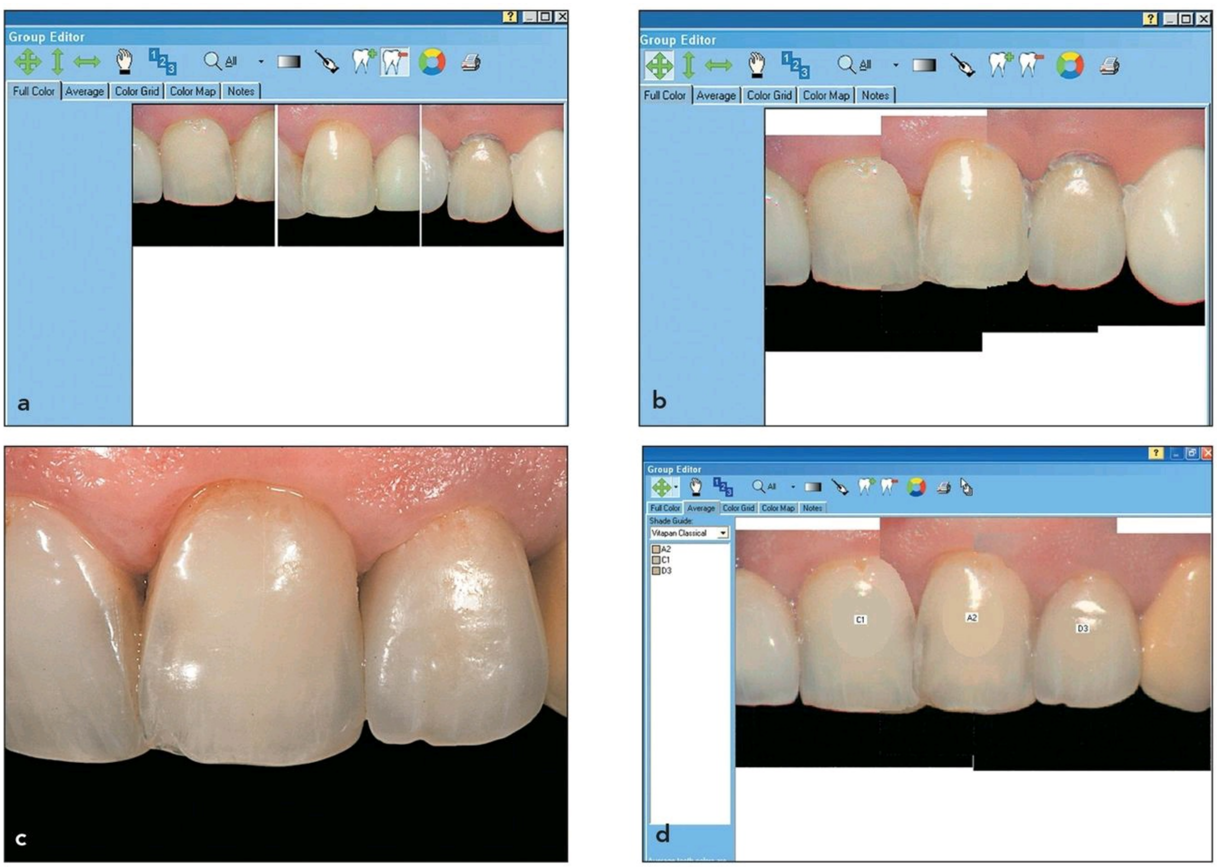


Fig 5-19 *The virtual try-in. This allows the lab technician to verify that the shade matches the tooth before it is sent back to the clinician. This saves time and frustration and increases productivity chairside, thereby making dentistry less stressful and more enjoyable. (a) Laboratory*

virtual try-in before images are combined. (b) Laboratory virtual try-in with images combined. (c) Clinical photo of restoration in place showing a good visual shade match. (d) Virtual try-in mocked up after restoration has been placed. Note how similar this is to the laboratory virtual try-in shown in (b), demonstrating the accuracy of this feature.

Verification

Verifying the shade of the restoration is significantly improved with advanced technology. The ShadeVision System, for example, has a virtual try-in feature (Fig 5-19), and the SpectroShade System has a restoration verification mode that allows the lab technician to verify the esthetics of the restoration electronically before sending it back to the clinician. This ensures the shade accuracy of the restoration prior to the visit and reduces the number of remakes and unnecessary patient appointments.

This electronic verification works with different systems. Even spot-measurement devices help the lab technician to verify the shade of a layered ceramic, but only in specific areas. This will simply give the technician guidance toward the correct shade.

Technology-Based Shade-Matching Protocol

The following recommended protocol is based on the use of ShadeVision technology. See Table 5-1 at the end of the chapter for more details on other digital shade systems.

1. Remove the instrument from the docking station
2. On the instrument's display screen, touch the tooth to be measured (Fig 5-20a).
3. Use your thumb and forefinger as a fulcrum to aid in aligning the tip against the tooth surface (Figs 5-20b and 5-20c).
4. Use direct vision to position the tip of the instrument on the tooth surface to be measured.
5. For the most accurate shade reading, position the ShadeVision tip so that it:
   - Rests against the tooth and gingival area and touches the tooth.
   - Is flush and square with the tooth surface.
   - Is parallel to the long axis of the tooth.
6. Press *Target* on the touch screen
7. Use the line-of-sight viewing window to adjust positioning while the bar graph counts down from 100% to 0%. You can reposition during this time. After it reaches 0%, hold the unit steady until you hear a beep.
8. Review image to confirm that:
   - It is centered on screen.
   - It is not blurred.
   - There are no artifacts from tongue, lips, opposing teeth, or from the operator's fingers.
9. Press *Accept* to proceed or *Cancel* to retake the image.
10. The work order is then sent to the laboratory via email, disk, or printed copy. If the work order arrives as an email, the lab technician can simply double-click to download the information to the ShadeVision database (Figs 5-20d to 5-20h).

In the laboratory:

11. Retrieve and print the work order information. Note that the ShadeVision system has an internal software analysis program that automatically defaults to lighter shade data. This gives the clinician and technician the option to increase the chroma and lower the value of the restoration if it is too light. (This is easier than lightening a restoration that is too dark.) The tooth is slightly lower in value and higher in chroma than a Vitapan D2 shade, which is the selected shade in this case (see Figs 5-20f to 5-20h).
12. Fabricate the restoration and verify its esthetics (Fig 5-20i).
13. Place the restoration in the ShadeVision restoration holder (Fig 5-20j). The restoration holder was designed specifically by X-Rite to assist lab technicians in verifying the accuracy of the restoration's shade. (Follow the same method to check the shade in steps 1-9).
14. All measured teeth should be reviewed and edited using the ShadeVision's software tools. When tooth definition is acceptable, click on the green check to proceed.
15. The Virtual Try-In feature allows the lab technician to visually check the restoration against the original images. If it matches on the monitor, it will match in the mouth (see Fig 5-19).
16. Confirm the work order information and add notes to send to the clinician if necessary.

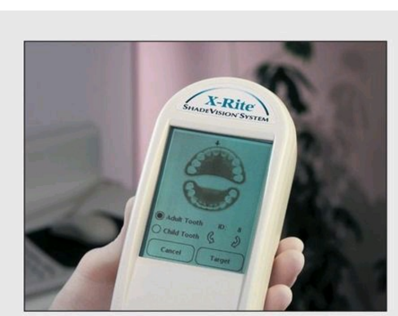


Fig 5-20a *Display screen of the ShadeVision instrument on which the tooth to be measured is selected by touch.*

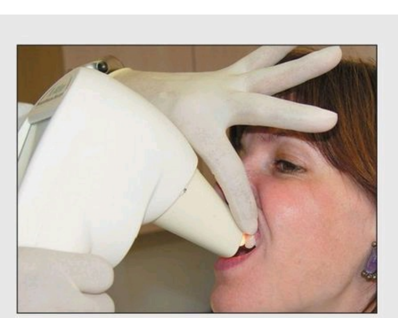


Fig 5-20b The instrument is placed against the tooth surface, using the thumb and forefinger as a fulcrum.

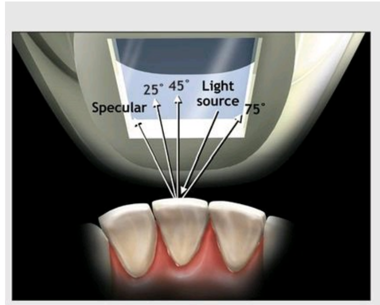
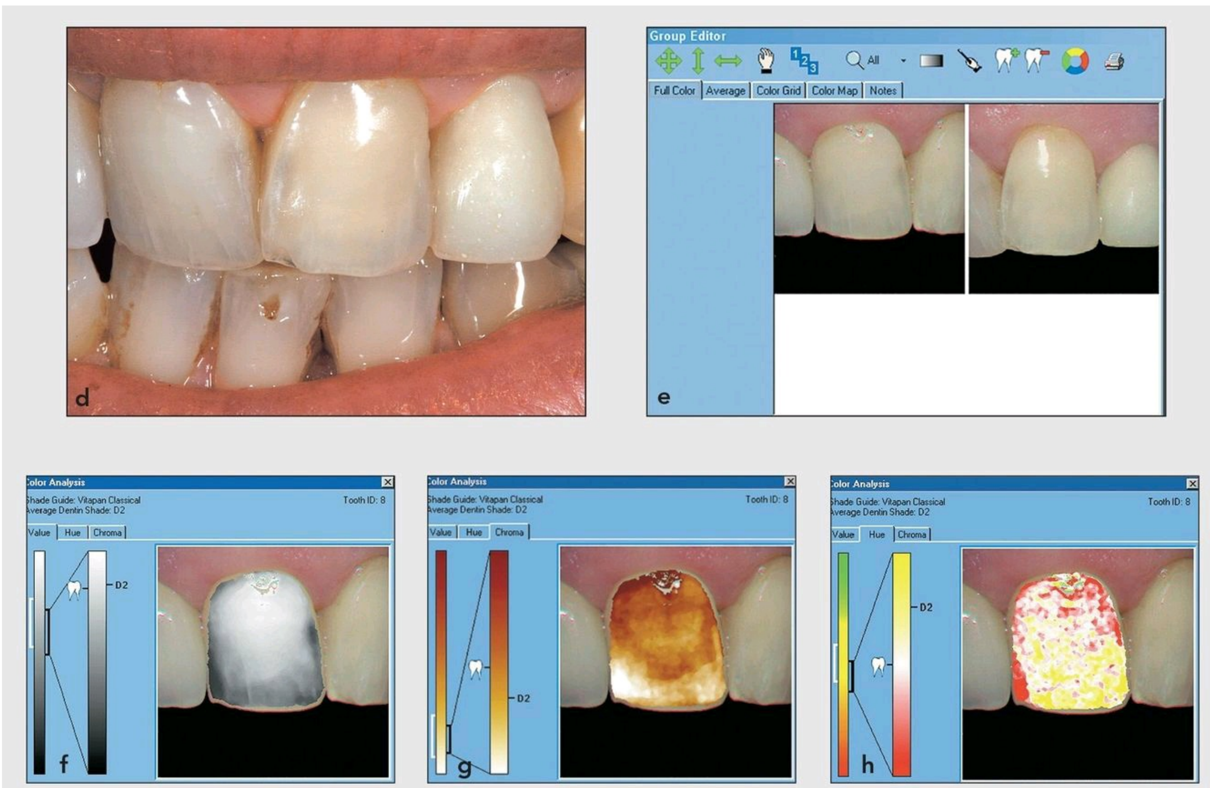


Fig 5-20c The tip of the instrument will read the properties of the tooth through various angles of reflected light.



Figs 5-20d to 5-20h With ShadeVision, digital color information can be communicated easily and accurately from the clinician to the lab technician via email.

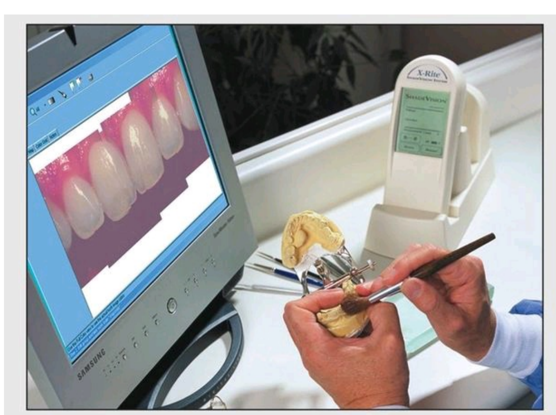


Fig 5-20i *The lab technician uses the digital shade data (with original photos uploaded using the Creation Wizard Restoration software) to fabricate the restoration.*

Fig 5-20j *The restoration is placed in the restoration holder and scanned in the laboratory. It is then cross-referenced and visually compared in the clinical pictures file. This is called the virtual try-in.*

Conclusions

Technology-based systems provide today's restorative dentist with a distinct advantage in creating highly esthetic, natural-looking restorations. The reports are less subjective, the capture of an image takes less time, and, with most systems, the shade of a restoration can be verified *before* it is sent back to the clinician. Table 5-1 presents a detailed breakdown of the systems currently available. The predominant disadvantage of these systems is cost, which might detract from their widespread appeal. Additionally, further clinical studies are necessary to document the effectiveness of digital shade taking. However, these systems provide an unbiased reading of shade and eliminate operatory distractions and the frailties associated with the human visual system. For this approach to be efficient, the laboratory must have the system as well, and indeed many commercial laboratories provide a shade-taking service. This quality control is a substantial advantage. The technician can verify that the color replication process was accurate for the shade requested, and, with the more sophisticated systems, a "virtual try-in" can be accomplished.

TABLE 5-1 Specifications for currently available technology-based shade systems†

Specifications	X-Rite	MHT/Degudent	Olympus	Vita	X-Rite/Degudent/ Dentsply
Product name	ShadeVision	SpectroShade Micro/Shadepilot	Crystaleye	Easyshade compact	Shade-X/ShadeStar
Measurement	Surface	Surface	Surface	Point	Point
Principle	Colorimeter	Spectro-photometer	Spectro-photometer	Spectro-photometer	Colorimeter
Portable	Yes	Yes	Yes	Yes	Yes
PC image	Yes	Yes	Yes	No	No
PC software	Yes	Yes	Yes	Yes	No
Virtual try-in	Yes	Yes	Yes	No	No
Email communication	Yes	Yes	Yes	Yes	No
Remarks		• Displays ΔE* • WLAN compatible		• Vita shades only	
Advantages	• Portable device • Easy handling and communi-cation • Good technical support	• High accuracy (reference system) • Measures differ-ence between closest shade tab and actual shade at virtual try-in	• Complete system with basic camera function	• Portable device • Patient comfort • Access to molar region	• Low price
Disadvantages	• Light reflections • Access to lower teeth • Resolution of monitor could be improved	• High price • Patient discomfort • No access to molar region	• High price • New on the market	• Incorrect posi-tioning can lead to poor results	• Very basic shade selection • No intermediate values

†The market penetration of digital shade systems is still low, and some products are marketed by several companies. The following sytems are no longer on the market or production and/or development have been suspended: Cynovad (ShadeScan), Shofu (ShadeEye NCC), DCM (iKam), Identa (Identa Color II), and Rieth (Digital Shade Guide).

Summary

- Analysis and communication of shade can be enhanced by technology-based systems.
- The three predominant categories of shade-taking technology are RGB devices, spectrophotometers, and colorimeters.
- New digital shade analysis creates a more objective standard for assessing shade while eliminating the distractions in the operatory.

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DIGITAL CHAPTER 6PHOTOGRAPHY

In this chapter:

- Equipment
- Settings
- Composition

Digital photography is a very broad subject that one could spend a lifetime exploring. It is hard to know where to start, especially when applying it to a specialty like dentistry. This chapter serves as an aid for the clinician during the process of integrating digital photography into the color-matching procedure.

The first step when starting to use digital photography is selecting the right camera. The great variety of products on the market makes it somewhat overwhelming to choose the proper equipment. Choosing a camera should be based on the intended use—in this case, as a precision tool for dental communication and to obtain a proper dental image that contains useful clinical information. It is critical that the image precisely records the color that is perceived by the eyes.[1] Correct color-rendition capture is essential for later color reproduction in dental restorations. Again, this is particularly difficult for the dental professional since as of yet there has been no standard established in the communication of digital images. Another necessary but potentially confusing step is the calibration of the camera, computer, and monitors, which should be performed in the office and in the laboratory. This procedure is time consuming and expensive, but considering that almost 90% of a shade is determined by the value (lightness), the importance of correct color reproduction should not be undervalued.[2]

Digital photography can be a valuable tool for the dentist and lab technician to use in quantifying shade; however, the use of a digital camera alone will not be effective for shade analysis. A shade-matching protocol using digital cameras, a gray card, and Adobe Photoshop has been described in the literature (see chapter 5). A combination of correct equipment, appropriate settings, and skilled composition will produce a usable image for communication.

Equipment

Producing the desired photographic result is dependent upon getting the correct exposure. Exposure is a product of light intensity and time. The amount of light entering the camera is controlled by the aperture in the lens and the speed at which the shutter in the camera body closes. It is the combination of the two, with the addition of a light-sensitive sensor setting, that generates the image. To achieve proper image quality for communication purposes, there is unvarying agreement that the digital single-lens refl ex (DSLR) camera is most suited for the purposes of medical, and specifically dental, photography[3] (Fig 6-1).

DSLR systems for clinical dental photography consist of three main components: camera body, macro lens, and a flash system. The combination of all three will generate a correct exposure (ie, image quality). Selecting the manufacturer is a personal preference, but Canon and Nikon tend to dominate the market.

Camera body

When choosing the camera body, it is not necessary to get the most expensive and technologically advanced model since many functions and features are not necessary for clinical dental photography; however, one should look for a charge-coupled device (CCD) or complementary metal-oxide semiconductor (CMOS) sensor, which will determine pixel quality. As early as 2002, various authors declared that with regard to resolution, the current technology had already surpassed the needs of the clinician.[4] At that time 3-megapixel cameras were the highest standard available. Today, 6-megapixel cameras are readily available and are more than sufficient, unless one is fastidious about image quality for later processing and printing. The number of pixels determines the size, not the quality of the image.

Lens

The factors that most affect image quality are the optical properties of the lens.[5] Note that, investing in an expensive lens is more important for image quality than investing in an expensive camera. In dental photography, images must be taken close to the subject. The focal distance needed for close-up photography is near the very end of the focal range for ordinary cameras.[6] This means the clinician should pay special attention to the lens in a camera. Macro lenses are recommended for close-up photography and designed to produce a 1:2 or 1:1 magnification so that the image captured is the same size as in real life. Macro lenses vary from 50 to 200 mm in focal length. A 100-mm lens is most commonly used in dentistry and is capable of taking close-up shots as well as portrait images. Using this focal length allows a working distance where one is able to control the light. If the camera is held too close, the light from the flash may not enter into the oral cavity, thus generating unwanted shadows.

Fig 6-1 *A digital camera system for dental use.*

Advantages and disadvantages of lenses for full-frame DSLR cameras

Full-frame DSLR cameras offer a number of advantages over their smaller-sensor counterparts. One advantage is that the wide-angle lenses designed for full-frame, 35-mm DSLR models allow for the same wide angle of view as that provided by wide-angle lenses designed for 35-mm film cameras. On smaller-sensor DSLR cameras, wide-angle lenses have smaller angles of view, equivalent to those of longer focal-length lenses that are often used in 35-mm film cameras. For example, a 24-mm lens on a camera with a crop factor of 1.5 has a 62-degree diagonal angle of view, the same as that of a 36-mm lens on a 35-mm film camera. On a full-frame DSLR camera, the 24-mm lens has the same 84-degree angle of view as it would on a 35-mm film camera.

However, full-frame DSLR cameras also present disadvantages. For example, if the same lens is used in both full-frame and cropped formats and the subject distance is adjusted to have the same field of view (ie, the same framing of the subject) in each format, the depth of field is in inverse proportion to the format sizes. This means full-frame cameras with the same f-number (ie, ratio of lens aperture diameter to lens length) will have less depth of field. Therefore, for the same depth of field, the full-frame format will require a larger f-number. (This can be changed using the f-stop settings on the camera.) This relationship is approximate and holds for moderate subject distances, breaking down as the distance with the smaller format approaches the hyperfocal distance and as the magnification with the larger format approaches the macro range. It is for this reason that full-frame DSLR cameras are not recommended for use in dental photography.

Flash system

A third component to consider when selecting a camera for clinical use is its electronic flash system. The most commonly used flash is a lens-mounted ring flash. The ring flash generates uniform light output and is useful for illuminating posterior regions or surgical procedures because it creates flat and shadowless images. With uniform bursts of light, however, many fine details are obliterated, making the image insufficient for color communication. Unidirectional, lateral flashes positioned on both sides of the camera at 45 degrees create shadows and highlights, which enhances the three-dimensional appearance of images.[6,7] Fine details such as translucencies, internal mamelon structures, crack lines, texture, and luster are captured, making it possible to duplicate them in the definitive prosthesis. Specialty mounting brackets allow for a variety of positions for the flash and expand the possibilities of illumination for a variety purposes.

Settings

After selecting the equipment, it is necessary to calibrate it for intraoral photography. Important settings to consider are white balance, depth of field, and exposure (Fig 6-2) (Box 6-1). As mentioned in the previous section, correct exposure is critical for capturing fine details of the teeth. Exposure is a product of aperture opening, shutter speed, and ISO (International Organization for Standardization) film/sensor sensitivity. The ISO should be set to 100 (or the lowest value the camera supports). The lower the number, the less grainy the image appears; however, more light will need to be delivered to the sensor. Additionally, shutter speed has to be set to 1/125 seconds or faster to eliminate any blurring caused by patient movements or shaking of the camera.

Aperture size, among other variables, also affects the outcome of a photo. It is controlled using f-stops, and the setting is recommended to be a minimum of f22. The importance of having a small opening is to gain adequate depth of field, which determines the extent of sharp focus. The next component that should be adjusted is the white balance. One reason that photographs often have a yellow or orange cast in incandescent (tungsten) lighting and a blue cast in fluorescent lighting is because different light sources emit light at different color temperatures (measured in Kelvin). A low color temperature shifts light toward red, and a high color temperature shifts light toward blue. In conventional photography, an orange or blue filter may be used to absorb the orange and blue light to correct for the imbalance. In digital photography, the photographer can use the image sensor to make that color shift. The most accurate method at achieving this is utilizing an 18% gray card in the custom setting menu. However, this is more common in professional photography; in everyday practice, using the flash white balance setting or directly selecting a temperature of 5,300 K is sufficient to accurately reproduce colors. The power output on electronic flashes also may need to be adjusted to one-half or one-quarter power, depending on the position and intensity of illumination of the flash. The latest cameras and flashes use through-the-lens (TTL) measurement, however, and do not need manual adjustment. Final corrections and fine-tuning of settings should be done to personal preference.

Additional settings

Current digital cameras offer many individual functions that can improve, but also compromise, the image output. For example, image size should be set to the maximum possible. This allows the whole sensor to be utilized when capturing images. The size of the image can be adjusted later on the computer if needed. The best file format to use in the dental field is JPG fine. Using the RAW format, mostly used in professional photography, is unnecessary. If the camera settings are used correctly, there is little that needs to be adjusted on the computer other than image size. Today's cameras have an optimized JPG compression that analyzes the image and selects the best compression in order to get the best quality. All cameras also now have built-in computers that process and optimize the images. To avoid any shift in color, the neutral setting should be selected. In most scenarios this will create somewhat pale images. but for the small color range used in dental photography, any boost of the image may result in an unnatural appearance. Another commonly used tool is the gridline display in the view finder, which helps to ensure the images are straight.

Box 6-1 **Basic camera settings**

Manual mode: M

Focus: Manual

Aperture: f22

Shutter speed: 1/125 s

ISO: 100

Image size: Maximum

File format: JPG fine

White balance: Custom (flash or 5,300 K)

Image optimization: Neutral

Flash output: One-half or one-quarter power (for non-TTL flash)

Options: Turn gridlines on for easier orientation

Fig 6-2 *Example of camera controls.*

Fig 6-3 *Magnification ratio of 1:2, with a 105-mm macro lens, is sufficient to capture approximately three teeth and three shade tabs in the photograph.*

Fig 6-4 *Including multiple shade tabs in the photograph helps the viewer to visualize deviations*

Fig 6-5 To achieve correct color rendition and surface reflection, shade tabs should be positioned directly above or below and on the same focusing plane as the teeth.

Composition

With well-calibrated equipment, it is up to the photographer to make the final adjustments needed to obtain an image that accurately transfers intraoral conditions. Manual focusing with specific magnification is recommended because automatic focusing often generates blurred areas where detail capture is necessary. As a rule, a magnification ratio of 1:2 is sufficient to capture approximately three teeth and three shade tabs in the photograph (Figs 6-3 and 6-4). It is important to set the magnification ratio first and then move the camera in and out to achieve proper focus on teeth as well as shade tabs. Positioning shade tabs above or below and on the same plane as the teeth, will help in correct color interpretation (Fig 6-5). Shade tabs that are positioned anterior to the teeth may be out of focus and will appear brighter because of stronger illumination from the flashes, generating false color perception.

Conclusions

A basic understanding of digital photography can yield great benefits in the shade-matching process. An accurate image will be helpful at many stages along the way from the initial shade selection to fabrication and verification. Additionally, high-quality reference photographs enable enhanced communication between the clinician and lab technician and ultimately lead to more successful restorations with fewer corrections.

Summary

- Digital photography is a valuable tool in shade matching and should be used according to the proper protocol, including gray cards and programs such as Adobe Photoshop.
- There are many factors to consider when selecting a digital camera, and the lens quality is perhaps the most important of these.
- Digital cameras have an array of settings, and the clinician can learn how to utilize these to take an optimal photograph.

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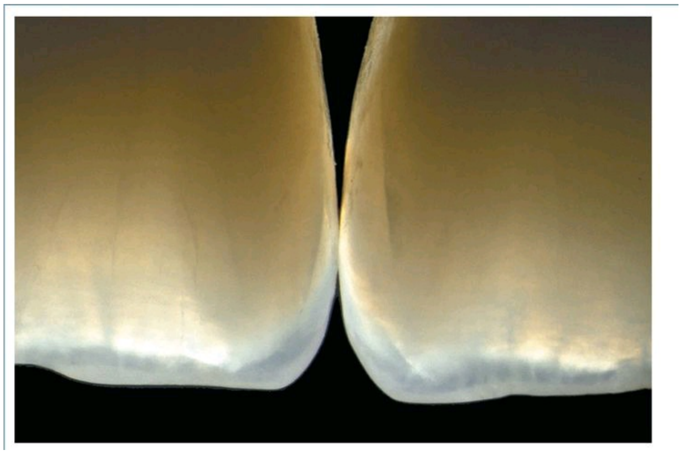
MATERIAL CHAPTER 7 SELECTION CHAPTER / Selection



In this chapter:

- Visual thresholds
- Color compatibility
- Color stability
- Color interactions
- Color matching with mixed or dissimilar restoration types

I magine having to place veneers on two maxillary central incisors of the same patient using two different composite resins. The color match between the composites and the adjacent teeth is perfect, and the same is true for the color match between the two composites. The patient is excited and extremely happy with the veneers. One year later, one of the veneers is still perfect, while the other turned a yellow-brownish color. This raises many questions in the patient's mind: Did the dentist forget something when restoring this tooth? Was the procedure too rushed? Was the dentist tired or overworked? Such an outcome can cause the patient to question the abilities of a dentist and hamper dentist-patient relations.

This "same hand, different outcome" situation is influenced by material selection, which largely determines the esthetics and longevity of a restoration. It is often difficult to discern the appropriate materials for a restoration. Many are similar in cost and appeal and make the same highly affirmative assertions in their advertisements. Personal experience, continuing education, and professional literature are the best ways to improve material-selection skills and avoid situations similar to the one described above.

Color-related properties of esthetic dental materials and human teeth can be divided into three categories:

1. *Color compatibility between dental material and teeth and among various dental materials*. This category includes color compatibility of shade guides.

2. *Color stability during reproduction or clinical placement and after placement (aging and staining)*. This category includes the effects of tooth whitening on teeth and dental materials.
3. *Color interactions*. This category includes color shifting of esthetic restorative materials because of blending (known as the *chameleon effect*), physical translucency, and masking potential/layering.

To better understand color compatibility, stability, and interactions, it is beneficial to first comprehend the meaning of color differences in dentistry through perceptibility and acceptability visual thresholds.

Visual Thresholds

As explained in chapter 5, the value ΔE* is a critical part of determining a correct shade match. While the ΔE* equation is sufficient for some fields, there is a more specified standard for dentistry. The *50:50% perceptibility threshold* is the color difference between compared objects that can be detected by 50% of observers; the other 50% of observers will notice no difference. A color match in dentistry is considered a color difference at or below the 50:50% perceptibility threshold. The 50:50% perceptibility threshold is fairly narrow and can be difficult to discern.

The *50:50% acceptability threshold* is the color difference that is considered acceptable by 50% of observers; the other 50% of observers would replace or correct the restoration because of a color mismatch. An acceptable color match in dentistry is a color difference at or below the 50:50% acceptability threshold.[1]

Depending on the task, conditions, and observer, the ΔE* that corresponds to 50:50% perceptibility threshold should be between 1 and 2, while the ΔE* that corresponds to the 50:50% acceptability threshold should be between 3 and 4.[2–6] After defining 50:50% perceptibility and acceptability thresholds, it is relatively simple to interpret color differences related to color compatibility, color stability, and color interactions. Color differences below the 50:50% *perceptibility* threshold are outstanding, while those below the 50:50% *acceptability* threshold are acceptable. The exceptions to this are blending and tooth whitening, where color difference above the 50:50% *perceptibility* threshold is acceptable and color difference above the *acceptability* threshold is outstanding.[1]

Fig 7-1 Acrylic (left) and ceramic (right) denture teeth of the same shade and by the same manufacturer. The acrylic tooth is lower in value, higher in red hue, and more chromatic.

Fig 7-2 *Composite resin samples of A2 shade by seven different manufacturers.*

Color Compatibility

The color compatibility of dental materials with the same shade designation will not necessarily be acceptable (Figs 7-1 and 7-2). In one study, a ΔE* greater than the acceptability threshold was recorded among the majority of different manufacturers' resin composites of the same shade designation.[7] Another study reported perceivable color differences between ceramic restorations made of the same shades by different manufacturers.[8] It was also found that ceramic denture teeth exhibit more pronounced color transitions as compared with monochromatic polymer-based denture teeth. Additionally, ceramic and resin shade guides frequently are not made of actual restorative material, which may result in unsatisfactory color compatibility.[9,10] Custom-made shade tabs fabricated with the actual batch of the chosen material are often needed to overcome color variations among batches of the same material.[11]

The *coverage error* (CE) corresponds to the mean color difference (ΔE*) between each evaluated natural tooth and the tab that matches best from a particular shade guide. CE is a convenient method of evaluation for how well dental shade guides match the color of human teeth. The smaller the CE, the better the shade guide and the chances of selecting an appropriate match. A good shade guide for fixed or removable prosthodontic restorations has a CE at or below the 50:50% acceptability threshold. A shade guide with fewer tabs and a higher CE may be sufficient for some direct restorative materials because of the color shifting that results from the blending effect and physical translucency.[12] Because of the variety of color measurement instruments and techniques, the absolute numbers reported as CEs of available shade guides differ. However, the bottom line is fairly clear: Vitapan Classical (Vita Zahnfabrik) and Trubyte Bioform (Dentsply) have the largest CEs, while Vitapan 3D-Master (Vita Zahnfabrik) has the smallest CE (ie, it matches natural teeth the best). CEs of other shade guides fall in between these extremes: Vintage Halo NCC (Shofu) is closer to the Vitapan 3D-Master, whereas Chromascop (Ivoclar Vivadent) and Vintage Halo (Shofu) are closer to Vitapan Classical.[12]

Color Stability

Dental materials can undergo color changes during fabrication. With dental ceramics, for example, firing and glazing can provoke these changes when the condensation method is employed.[8,13,14] Color shifts at the time of placement are related to polymerization or other types of setting of direct restorative materials.[15] Polymerization-related color shifts of composite resins and glass and hybrid ionomer materials can be very pronounced (ΔE* >10).[16,17]

Fig 7-3 *Blending effect of Estelite Σ (Tokuyama America) resin composite: A1 (top left), A3 (top right), and A3 (bottom) with central part filled with A1 to mimic Class 1 restoration.*

While dental ceramics exhibit good color stability after placement, some other materials undergo more pronounced color shifting. Color stability after placement is related to factors such as aging, staining, and bleaching. Extrinsic color changes (staining) occur when dental materials (composite resins, glass and hybrid ionomers, cements, interim materials, etc) are exposed to foods, mouthwashes, home bleaching agents, fluoride varnishes, and cigarette smoke.[18] Accelerated aging of composite resins produced changes in color (ΔE*) that ranged from minimal to very visible as compared with baseline.[19] Composite resins can also undergo color and appearance changes after bleaching, which sometimes works out favorably if the color shift occurs in the same direction as the color shift of the tooth.[20] Other studies have reported substantial aging-dependent color changes of resin cements and interim materials.[21,22]

Surface roughness and gloss are also important for the long-term esthetics of composite restorations.[23] The smooth surface of a restoration provides low plaque accumulation and ensures its longevity by preventing recurrent decay and periodontal disease.[24,25]

Color Interactions

Color interactions between tooth and dental material or between different dental materials, especially those related to a layering and/or blending effect are usually beneficial (Fig 7-3). They make restorations more lifelike and can reduce color difference between the material and hard dental tissues. Some exceptions are when metal or underlying discoloration needs to be masked.

Layering techniques are used for fabrication of ceramic crowns, denture teeth, and direct and indirect composite restorations. A proposed method for quantification of color shifting due to layering of dental ceramics involves calculating the color change resulting from placing a 1-mm layer of body porcelain over an opaque porcelain.[26] This principle can also be applied to or adjusted for other restorative materials.

The *blending effect* (sometimes referred to as the *chameleon effect*) refers to the perceived color difference between esthetic dental materials and hard dental tissues. The color difference is smaller when they are observed together than when they are viewed in isolation.[27,28] The blending effect works in the clinician’s favor since it neutralizes, to a certain extent, color mismatches caused by human error or the absence of an adequate shade in a shade guide. It was found that the blending effect on composite resins increased in proportion to the decrease in the restoration size, a decrease in the initial color difference, and an increase in translucency.[29,30]

Fig 7-4a *The lower anterior depth preparation bur is used to provide minimum reduction so that the stump shade can be used as the colored canvas to match the veneer restorations.*

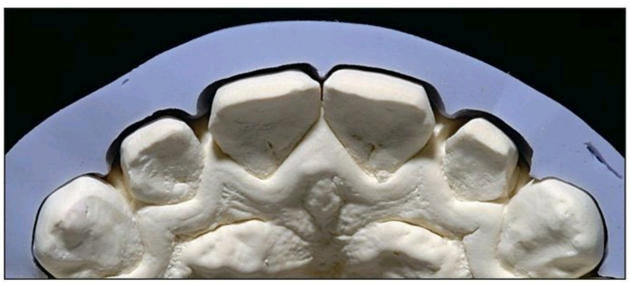


Fig 7-4b *A facial silicone matrix is used to verify uniform tooth reduction.*

Fig 7-4c *The ceramic veneers are fabricated with a default uniform thickness of material, thereby controlling the color of the definitive restorations.*

Fig 7-4d *Predictable color transition is achievable with uniform reduction and thickness of the ceramic veneer restorations.*

Color Matching with Mixed or Dissimilar Restoration Types

In this age of minimally invasive dentistry, the use of partial- and extended-preparation bonded ceramic restorations[31–34] has become standard practice. Often a clinician will be faced with intra-arch treatment-planning decisions involving mixed or dissimilar restoration types, such as the use of crowns and veneers within the same dental arch. Understanding the esthetic and biologic ramifications of a full-coverage tooth preparation and recognizing when this choice may not be in the best biologic interest of the patient is important. Additionally, with increased awareness of dental procedures, patients frequently oppose having their teeth prepared for full-coverage restorations in an effort to achieve an acceptable color match. This can make color matching of dissimilar restorations types even more challenging.

The evolution of new materials and techniques, however, means that the goal of matching dissimilar restorations types is not impossible. Technicians understand that correct color matching with veneers can be achieved if the underlying dentin, or *stump shade,* is without color flaws or irregularities and, most importantly, if the preparation/tooth reduction is of a uniform thickness.

Controlling color matching is therefore a function of uniform tooth reduction and ceramic thickness.[35] The stump shade also can be useful in achieving the correct color match in a single tooth or in multiple ceramic veneers (Fig 7-4). The stump can be envisioned as a canvas on which the technician can paint and create the appropriate ceramic veneer.

Fig 7-5a *Existing interproximal defective composite resin restorations that will require removal and incorporation into the definitive ceramic veneer restorations.*

Fig 7-5b *Non-uniform reduction of the preparations due to recurrent decay and defective interdental restorations between the mesial of the maxillary right lateral incisor and the distal of the right central incisor.*

Fig 7-5c *The proper stump shade is selected intraorally.*

Fig 7-5d *Ceramic buildup used to achieve uniform size, shape, and shade of the preparation to match that of the maxillary left central and lateral incisors.*

Frequently, non-uniform tooth reduction or preparation occurs when existing defective interproximal restorations are present and must be replaced within the ceramic veneer restoration itself (Fig 7-5). By understanding that variations in tooth reduction and ceramic thickness can negatively impact the color and translucency of the definitive restoration, the technician learns to control these parameters by also understanding and adjusting for the influence of light dynamics on the ceramics used. Working with ceramics is a subtle art, and mastering the influence of color and translucency is critical for predictable color-matching outcomes.

Fig 7-5e *The ceramic is fired and evaluated for the proper stump shade on the refractory die.*

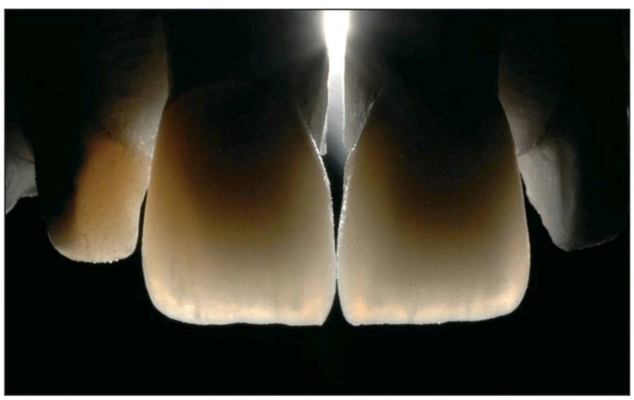


Fig 7-5f *Understanding ceramic masses is imperative to achieve proper light dynamic properties in the non-uniform areas of tooth reduction.*

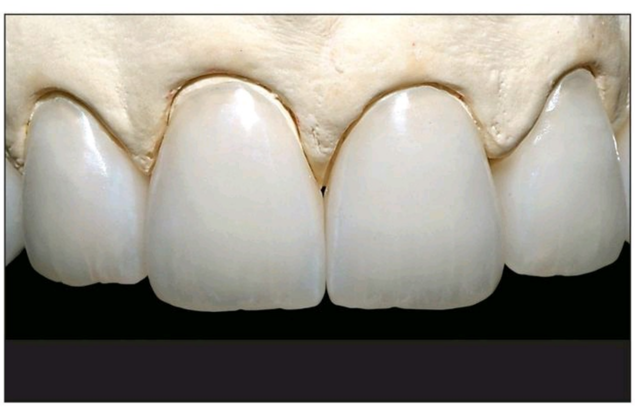


Fig 7-5g *Uniform color and translucency is achieved despite non-uniform reduction of the*

maxillary right lateral and central incisors and uniform reduction of the maxillary left lateral and central incisors.

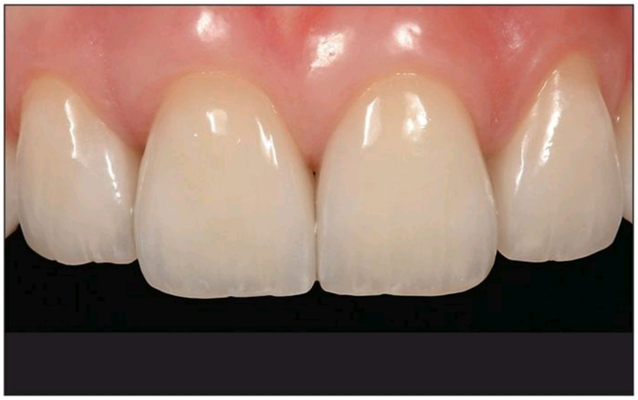


Fig 7-5h *Postcementation/bonding demonstrating a uniform color blend and transition.*

Technicians and clinicians also frequently are faced with having to make the veneers first and then must try to match the less translucent crown. This is a difficult task, and the technique is not predictable. It has also been attempted to make the veneers slightly more opaque in an effort to potentially match the more opaque crown but this also required multiple visits.

The same concepts described for color matching of veneer restorations can also be applied to crown-veneer intra-arch mixed restorations.[36] The canvas of the tooth must be calibrated or *equalized*. The *canvas equalization technique* (CET) is for exactly matching the veneer preparation in accordance to three major factors: size, shape, and shade (the three *Ss*).

Fig 7-6a *Cast of mixed restoration type preparations.*

Fig 7-6b *Detailed documentation of laminate preparation using ceramic dentin shade tabs.*

Fig 7-6c *Color modifiers are layered and fired onto the zirconia coping to match the inner tones of the full crown preparation.*

Fig 7-6d *Ceramic masses applied to add volume and correct density for light dynamics. Note the layering/buildup of the ceramic is intended to match the size and shape of the veneer preparation of the maxillary right central incisor.*

Once corrections of the coping substructure are made according to the three *Ss*, then a layer of veneering ceramic with consistent width can be placed accordingly. This controls the final shade of the restorations because the thickness of veneering ceramic is controlled (Fig 7-6). The canvas equalization technique is not dependent upon the use of any particular substructure material, which gives it great versatility. It should be noted that restorations should not match on the stone die cast since the color of the stump shade has not been factored in; in fact, a nonmatch on the cast is indicative of a potentially good clinical match. This technique can streamline the number of visits and procedures required to achieve a predictable color match of mixed and dissimilar restoration types.

Fig 7-6e *Canvas equalization technique (the three Ss–size, shape, and shade). The size and shape are established with the ceramic buildup using shoulder porcelain, which is more stable during subsequent firing cycles of veneering ceramic application.*

Fig 7-6f *The shade is established and checked for further processing if necessary before the layered veneering ceramic is applied.*

Fig 7-6g *Nonmatch on the cast is evident between the full crown and laminate restorations, which is to be anticipated if the technique is properly followed.*

Fig 7-6h *Acceptable match after placement, using the tooth structure as the canvas for the laminate veneer restorations.*

Special considerations for direct composites

Though many regard ceramics as the restorative material of choice, composite materials have been gaining favor because of their excellent esthetic potential, acceptable longevity, and relatively low cost.[37,38] In addition, direct composites allow for minimally invasive preparation or require no preparation and are indicated for Class 3, 4, and 5 restorations and for esthetic correction of tooth form, dimension, and color.

Modern fabrication of composite restorations is based on the natural layering concept.[39,40] This approach embraces the typical optical and anatomical characteristics of natural teeth[37,39,41] and emphasizes the importance of using materials specifically designed to emulate the dentin and enamel, respectively. According to this concept, the dentin replacement materials should be characterized by:

- Single opacity
- Large chroma scale
- Single hue
- Fluorescence

The enamel replacement materials should mimic the different kinds of natural enamels, which for practical reasons are classified into three types:

- Young enamel: White tint, high opalescence, lower translucency
- Adult enamel: Neutral tint, less opalescence, intermediate translucency
- Aged enamel: Yellow or grayish tint, higher translucency

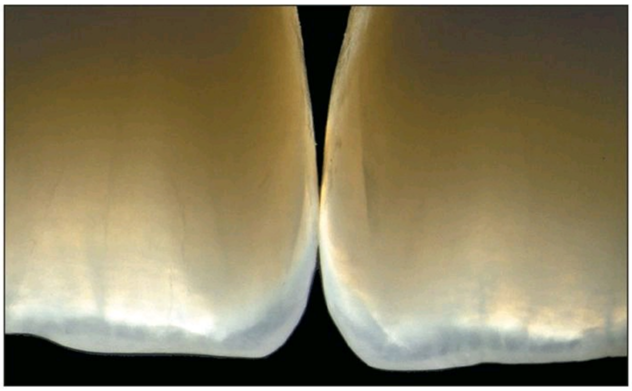


Fig 7-7 Transillumination of natural teeth, showing the enamel as a translucent shell around the colored dentin.

Of course, identification of the optical characteristics of dentin and enamel is of considerable interest for the development of any tooth-colored material (Fig 7-7).[42,43] Master ceramists and manufacturers of dental porcelains devote significant time and effort to developing powders that will mimic these two main constituents of natural teeth.[44] However, ceramics are used to veneer a metal or ceramic framework in thin layers—a configuration that does not correspond to the arrangement of natural tissues. The anatomy of composite restorations, on the other hand, more closely resembles that of a natural tooth; therefore, the natural tooth can be used as a model for analyzing or developing a composite system.

Specific layering concepts

Four different layering concepts have guided manufacturers in the development of their composite materials. [45] Each concept is based on the specific arrangement of the two or three layers usually needed for large Class 3 and 4 restorations or incisal buildups.

1. Basic layering concept: Includes one or two sets of shaded materials (with different opacities but the same chroma range) for the main restoration volume, completed by a limited number of incisal or transparent materials (eg, Prodigy [Kerr]) (Fig 7-8).
2. Classic layering concept: Provides one basic set of shaded materials for dentin replacement (with approximately the same opacity and chroma) and two layers of enamel replacement materials, including shaded enamel and incisal materials (eg, Herculite [Kerr]) (Fig 7-9).
3. Modern layering concept: Uses two shaded materials (with different opacity levels) for the replacement of dentin as well as a series of enamel materials (eg, Esthet-X [Dentsply]) (Fig 7-10).
4. Trendy layering concept: This is the most recent but certainly the most promising concept. It relies on the application of two basic dentin and enamel materials that closely replicate the optical properties of natural tissues and allows for effect materials to be placed between them to create a spatial arrangement that is identical to natural tooth anatomy (eg, Miris [Coltène] or Vitalescence [Ultradent]) (Fig 7-11). Shaded dentin materials are available in a single hue (ie, the universal dentin shade, close to Vita A) with a large range of chroma (usually beyond the existing Vita range) and exhibit an opacity close to that of natural dentin. The use of intensive colors or effect materials helps to replicate specific anatomical peculiarities and improve final

esthetic outcome. The most useful effect materials are blues (reinforcement of composite natural opalescence), gold-yellows (for a local increase of restoration chroma), and whites (for simulating white spots or hypocalcifications) (Fig 7-12). This approach not only is clinically appropriate but also has excellent esthetic potential.

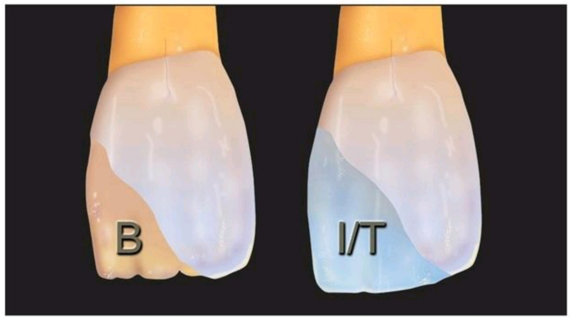


Fig 7-8 *Basic layering concept. The body material (B) is covered by an incisal or transparent material (I/T).*

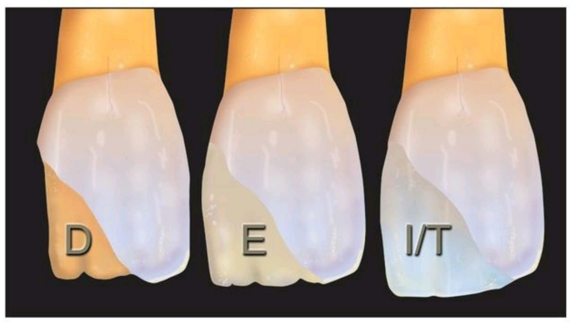


Fig 7-9 *Classic layering concept. The bulk of the restoration is made of two colored materials with differing opacities. The first, dentin (D), is more opaque and has a higher chroma; the second is a so-called enamel (E). Finally, the surface is covered by an incisal or transparent material (I/T).*

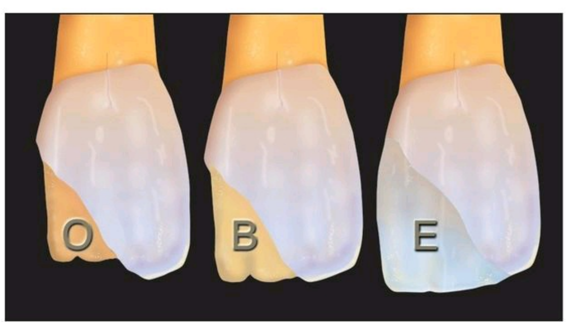


Fig 7-10 *Modern layering concept. There are two dentin materials: The first is opaque (O) and is placed in the most interior part of the preparation; the second is less opaque and is used as the body material (B). Enamel materials (E) are used on the surface.*

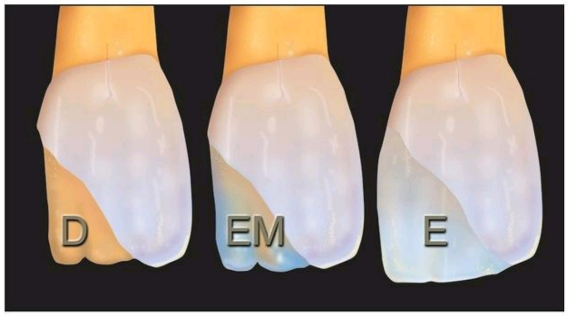


Fig 7-11 *Trendy layering concept. The restoration is made from two distinct materials that mimic the position and optical properties of dentin (D) and enamel (E). Effect materials (EM), which are placed between the dentin and enamel materials, complete the system and provide improved esthetics.*

Fig 7-12 *Miris shade guides for internal characterization (ie, effect materials).*

Fig 7-13a Teeth are cleaned with a nonfluoridated prophylaxis paste.

Fig 7-13b *Miris shade guide for dentin, following the natural layering concept.*

Fig 7-13c *Selection of dentinal chroma. A series of dentin tabs are placed close to the tooth in order to determine the most appropriate dentinal chroma.*

Fig 7-13d *The choice of dentinal chroma is confirmed by placing the composite tab close to the cervical area, where there is the least amount of enamel.*

Shade selection protocol

According to the natural layering concept, the following four steps should be involved in shade selection for direct composite restorations:

1. Cleaning of the teeth using a prophylaxis paste (Fig 7-13a)
2. Selection of dentinal chroma in the cervical area (where enamel is thinnest) using samples of the composite material (Figs 7-13b to 7-13d)
3. Selection of enamel tint and translucency by simple visual observation (Fig 7-13e)
4. Combination of both samples to demonstrate the final restorative effect and confirm an esthetic match (Figs 7-13f to 7-13h)

Figure 7-14 presents the shade selection for a case in which the trendy layering concept was used in the direct composite buildup of a peg-shaped lateral incisor.

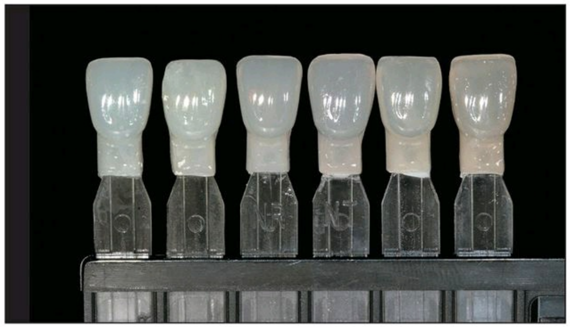


Fig 7-13e *Miris shade guide for enamel. The enamel shade tab is selected by visual observation. No attempt is made to select enamel by comparing the composite sample with the tooth.*

Fig 7-13f *A thin layer of glycerin gel is placed in the selected enamel shade tab before the dentin tab is inserted.*

Fig 7-13g *The combined enamel and dentin shade tabs are compared to the teeth to determine whether there is an accurate shade match.*

Fig 7-13h *Result after 2 years.*

Fig 7-14a *Preoperative view of a peg-shaped maxillary right lateral incisor with a discolored mesial restoration.*

Fig 7-14b *Dentin shade selection.*

Fig 7-14c *The enamel shade with the dentin tab inserted (using glycerin gel) is compared to the tooth to be matched.*

Fig 7-14d *Lateral incisor following decay excavation.*

Fig 7-14e *Buildup of palatal enamel wall.*

Fig 7-14f *Buildup of dentin and labial enamel following the natural layering concept (note the use of blue effect materials next to the incisal edge).*

Fig 7-14g *Postoperative view.*

Conclusions

Improvements of dental shade guides and related restorative materials can result in enhanced esthetics of dental restorations. The considerations mentioned in this chapter are associated with the application of color science to material selection in dentistry in order to complement the artistic talents of clinicians and ceramists and provide an appropriate foundation and a frame for their artwork.

Summary

- Depending on task, condition, and observer, perceptibility and acceptability thresholds in dentistry are $\Delta E^* \approx 1$ to 2 and $\Delta E^* \approx 3$ to 4, respectively.
- Color compatibility between restorative materials is critical, particularly for mixed restorations. Among dental shade guides, Vita 3D-Master corresponds to color of natural teeth the best.
- Color stability during and after placement can significantly influence the esthetics of a restoration and forecast the longevity of the restoration's color.
- Color interactions associated with layering and blending can improve the esthetics and appearance of restorations.
- Dental materials can be either friend or foe; therefore, the material selection is very important for the final esthetic outcome in dentistry.

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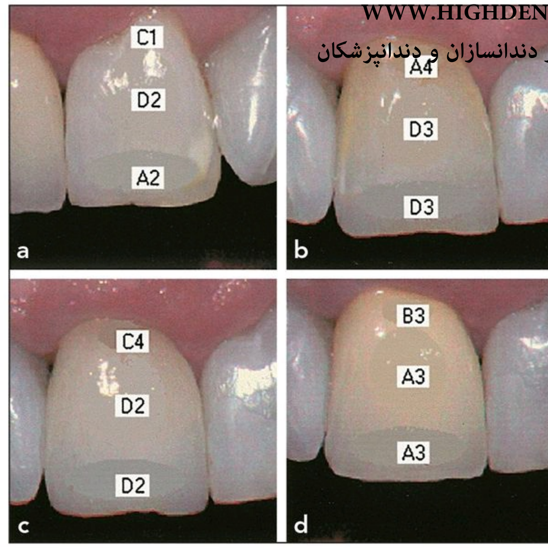
PREDICTABLE COLOR REPRODUCTION

CHAPTER 8

In this chapter:

- Seven steps to a successful shade match

Fig 8-1 *Conventional methods of shade selection, when used alone, have several pitfalls, the most significant of which is inaccurate analysis by the clinician. Frequently, multiple restorations are made for the same case, which is an extremely time-consuming and unproductive process. Two crowns were made for the implant abutment at the site of the maxillary right central incisor with an incorrect match: The crown in (a) is too opaque and yellowish, and the crown in (b) is too low in value (gray).*



***Figs 8-2* and 8-3** *Technological shade information also has limitations when used by itself. The three crowns shown in Fig 8-2 (left) were made for the maxillary right central incisor of the same patient without success. The ShadeVision (X-Rite) comparative shade map report in Fig 8-3 (right) shows the discrepancies in shade between the tooth being matched (a) and all three restorations (b to d).*

Previous chapters have described the recommended protocols for shade matching using a conventional approach (chapter 4) and a technology-based approach (chapter 5); yet each method, when used by itself, affords limited clinical success. Shade determination using only conventional methodologies often results in failure, frustration, and multiple remakes (Fig 8-1). In addition, although advances in technology have greatly increased the likelihood of a clinically acceptable shade match through accurate shade analysis, shade matching using technological shade systems alone has limitations in the amount of visual information that is provided to the technician (Figs 8-2 and 8-3).

Following much research and clinical evaluation,[1–3] this chapter outlines the authors' recommendations for a more objective and predictable approach to shade matching: a combination of conventional techniques with new technologies.

Fig 8-4a *Clinical photo of the maxillary central incisors after vital tray bleaching. Twelve years prior to the current treatment, the patient had a post-core foundation restoration and a metal-ceramic crown placed on the left central incisor following root canal treatment. The midfacial gingival margin tissue is starting to develop a slight recession defect, which, along with the poor color match, has caused the patient to seek replacement of the restoration.*

Seven Steps to a Successful Shade Match

By now the complexity involved in matching a shade is clear. The variables in the operatory and human error are recognized obstacles, and color, being both a science and an art, often can be difficult to gauge. Recognizing that fact, the following case study showcases the best way to take a shade using technology, shade tabs, and reference photography, a combination that will increase esthetic success.

1. Preoperative patient evaluation

The following questions should be considered during the preoperative patient evaluation:

- Are there any contrast effects present that may affect color perception?
- How will the shade selection of one restoration affect the overall smile?
- Is there a significant variance in the shade of the gingival, body, and incisal sections of the teeth?
- Can the patient's teeth be categorized as high in translucency or high in opacity?
- Will material selection significantly affect the final esthetic outcome of the restoration?

Once these questions have been addressed, a treatment plan can be developed, and the clinician can determine the ideal material selection for the case (see chapter 7).

2. Analysis

As outlined in the previous chapters, the best way to analyze the shade is to use all of the tools available. Technology, shade tabs, and reference photographs should all be employed to ascertain the precise shade. First, technology should be used to determine both an overall basic shade as well as shades for each of the three sections of the tooth (gingival, body, and incisal) (Figs 8-4a to 8-4e). Shade tabs can then be used to visually confirm the technological shade analysis. In addition, contrasting shade tabs (light and dark) should be used to allow the clinician to better determine and communicate the value of the restoration to the technician.

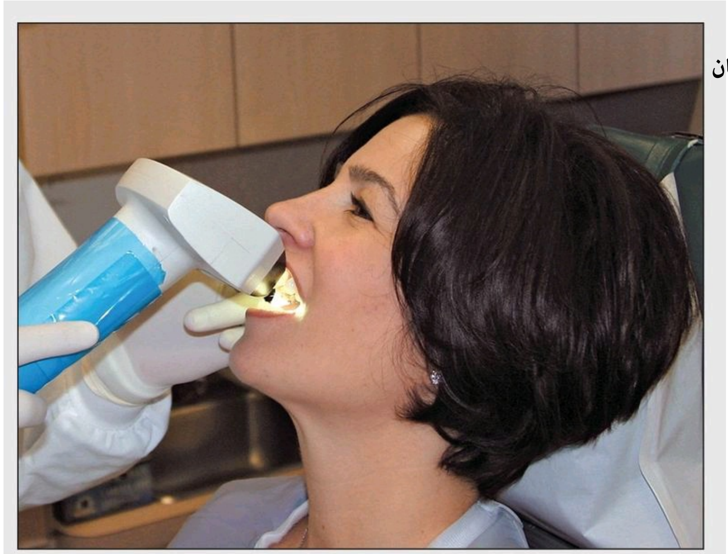


Fig 8-4b *SpectroShade (MHT Optic Research) unit during image capture.*

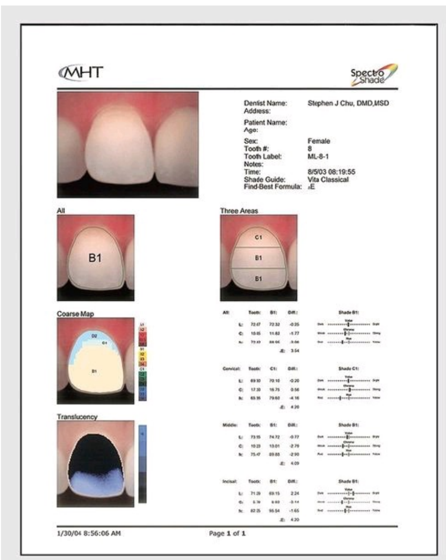


Fig 8-4c *SpectroShade comprehensive report for the reference tooth (maxillary right central incisor). Coarse (basic), fine, gingival/body/incisal (GBI), and inferred translucency maps are provided.*

Fig 8-4d *A basic Vita B1 shade (Vita) is found for the reference tooth.*

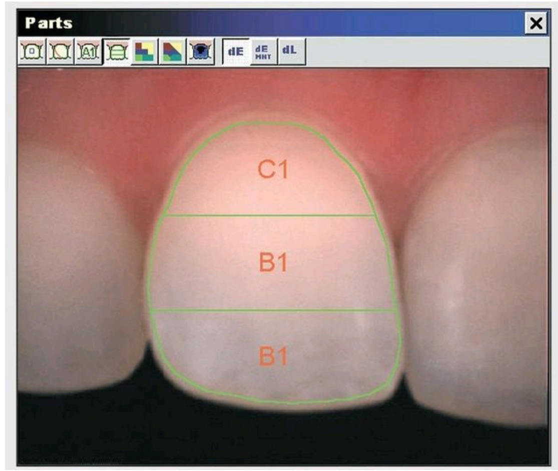


Fig 8-4e *GBI shade report shows Vita C1 shade in the gingival third and B1 in the body and incisal thirds of the reference tooth.*

Fig 8-4f *Shade tabs are used to visually confirm the findings of the technology-based shade analysis reports. Here, Vitapan shade C1 (Vita) is referenced based on the gingival shade found by the SpectroShade system. The shade tabs were photographed using twin spot flash from the sides.*

Fig 8-4g *Vitapan B1 shade tab with twin flash from the sides.*

Fig 8-4h *Vitapan B1 shade tab with flash from the top.*

Fig 8-4i *Vitapan B1 shade tab with flash from the bottom. Note the change in visual shade comparison when flash orientation is changed (Figs 8-4g to 8-4i).*

3. Communication

The clinician should take reference photographs of the shade tabs suggested by digital analysis (Figs 8-4f to 8-4i), as well as the extreme shade tabs (Fig 8-4j) next to the dentition to be matched. In addition, reference photographs showing the full smile and the shade of the surrounding dentition should be taken. It is important to remember to take such photographs from varying angles and under different lighting conditions to best capture the subtleties of the tooth shade and texture (Fig 8-4k). An 18% reflectance gray card should also be used as a background in reference photography to eliminate extraneous color distractions and contrast effects (see chapter 3).

Once the shade information is gathered by the clinician, it must be delivered to the laboratory. The technology-based analysis can be delivered electronically. Reference photographs and written descriptions, critical pieces of information for accurate shade communication, may be sent to the laboratory as hard copies or as electronic files by email or on CD.

Fig 8-4j Composite photograph with extreme shade tabs to assess value change. (left to right) Chromascop bleached shade 010 (Ivoclar-Vivadent), Vitapan B1, and Vitapan B4.

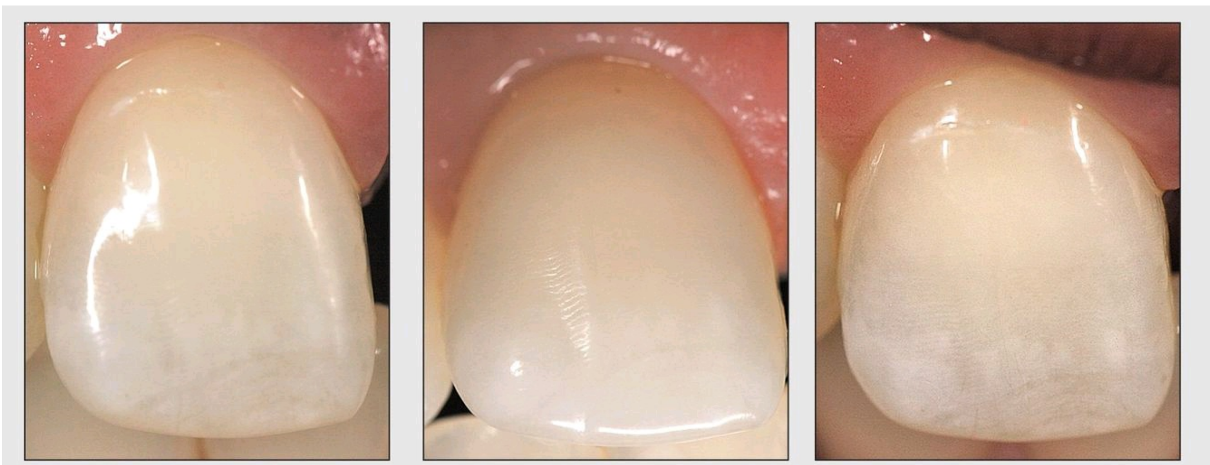


Fig 8-4k Photographs of the maxillary right central incisor (reference tooth) with lighting from the side (left), the bottom (center), and the top (right), showing nuances in tooth shade and characterization.

4. Interpretation

The laboratory must interpret all of the pieces of shade information provided. The reference photographs help the lab technician to better understand the shade tab selection and the variance in value and chroma, while the digital color map provides a detailed depiction of the shade reading. The technician translates this information into the language of the ceramic system to be used, creating maps of where the ceramic system's special effects powders should be used to achieve the desired nuances in shade (Figs 8-4l to 8-4n).

Most technicians are familiar with the various nomenclatures and effects of different porcelain systems. This knowledge allows them to select the best ceramic system for the esthetic restorative needs of each clinical case.

Fig 8-4l An 18% reflectance gray card is also used in the dental laboratory by the technician to assess the value differences in shade tabs seen in the reference photographs.

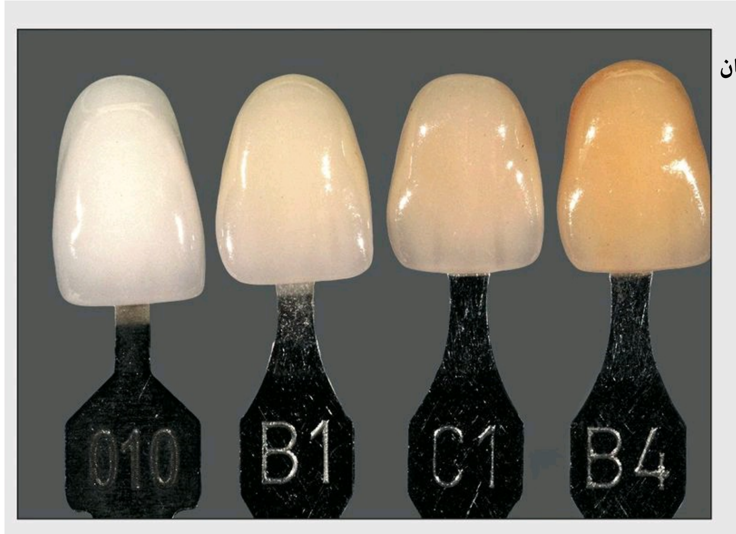


Fig 8-4m *Shade tab information is interpreted and converted into the language and nomenclature of the ceramic system used.*

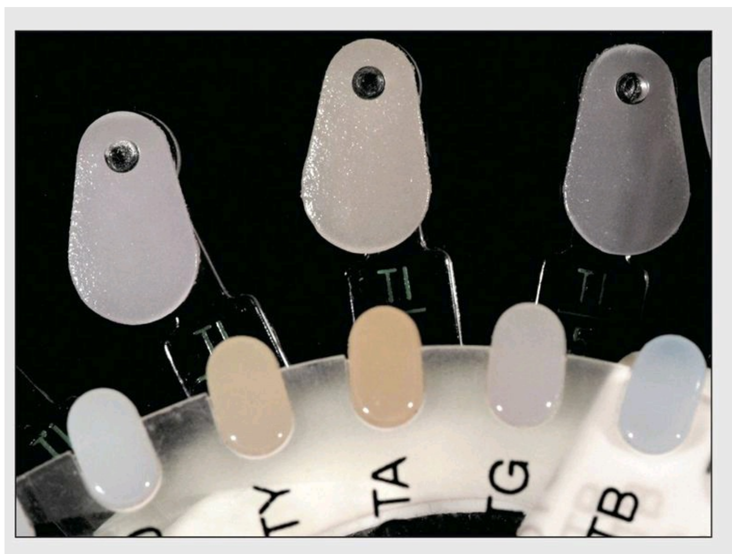
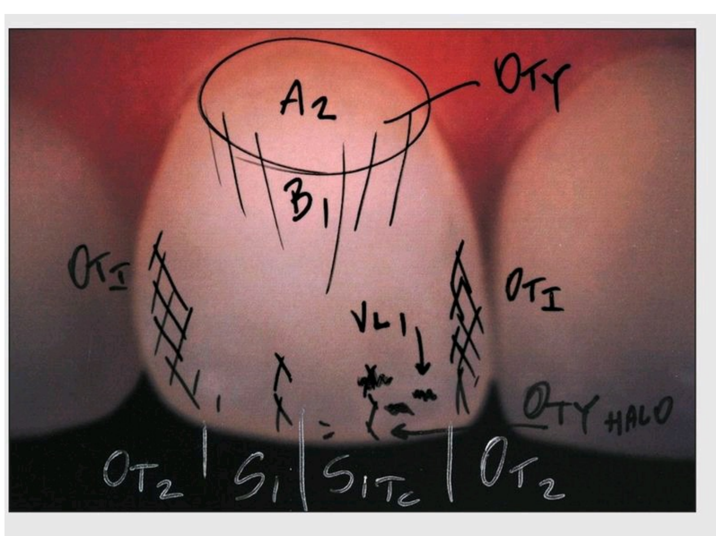


Fig 8-4n *The language of the ceramic system is transposed onto a printout of a clinical photograph to create a special effects color location and distribution map.*



5. Fabrication

After assessing the shade and determining what material works best given the particular clinical application, the lab technician fabricates the restoration and adds the necessary details in the staining and glazing stage to match the opposing dentition (Figs 8-4o to 8-4y).

Fig 8-4o *Ceramic powders are selected and mixed to a creamy consistency with modeling fluid.*

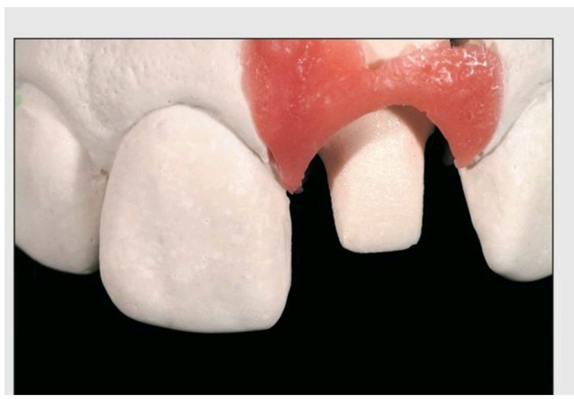


Fig 8-4p *A refractory cast with simulated soft tissue is fabricated for buildup of an all-ceramic crown.*

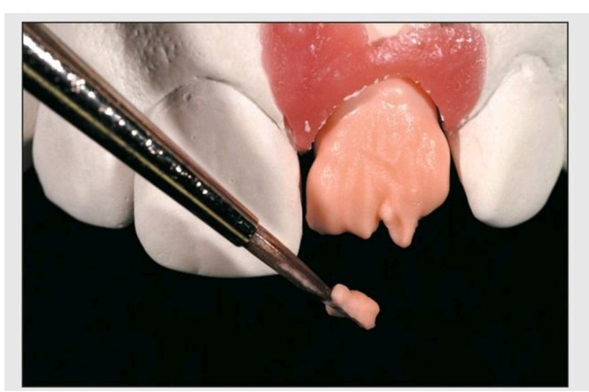


Fig 8-4q *Secondary dentin is layered at the cervical area, then dentin is layered on top and blended toward the body and incisal areas.*

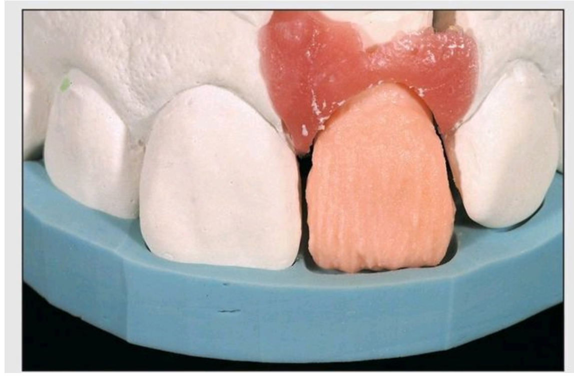


Fig 8-4r *An incisal matrix is used in the dentinal ceramic buildup to guide the vertical and horizontal incisal edge positions.*

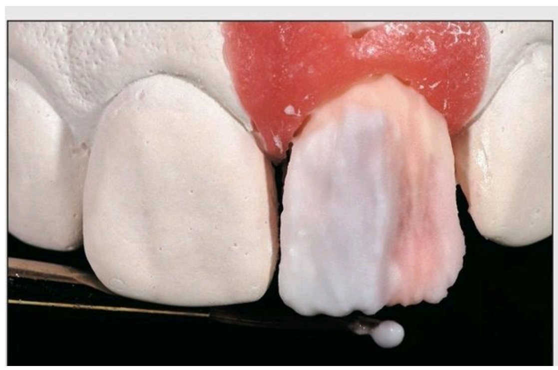


Fig 8-4s *Dentin ceramic material is layered with incisal enamel and special effects (opal transparent) powders.*

Fig 8-4t *Crown after completion of first bisque bake.*

Fig 8-4u *Second ceramic buildup with opal transparent powders (HeraCeram [Heraeus-Kulzer]).*

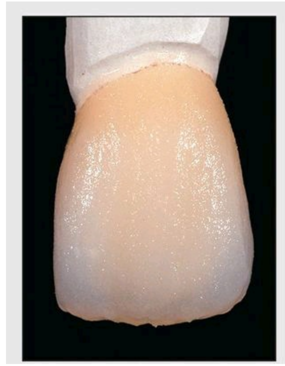


Fig 8-4v *Crown after second bisque bake with opalescent powders.*

Fig 8-4w *Final shaping of restoration with a red wax-based pencil. A lead-based pencil should not be used because the lead dust can contaminate and discolor the porcelain.*

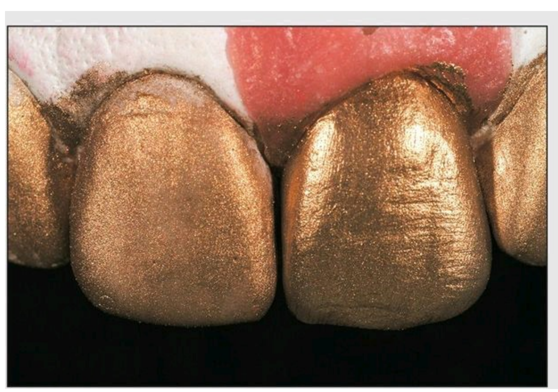


Fig 8-4x *Gold powder is used to visualize the surface texture of the restoration.*

Fig 8-4y *The restoration is glazed for characterization and polished to give the proper surface luster.*

6. Verification

The shade is verified using both conventional and technological methods (Figs 8-4z to 8-4hh). If the restoration does not match, extrinsic colorants are used to adjust the shade, then the virtual try-in and shade tab comparisons are repeated. Once accuracy is confirmed, the restoration is sent back to the clinician.

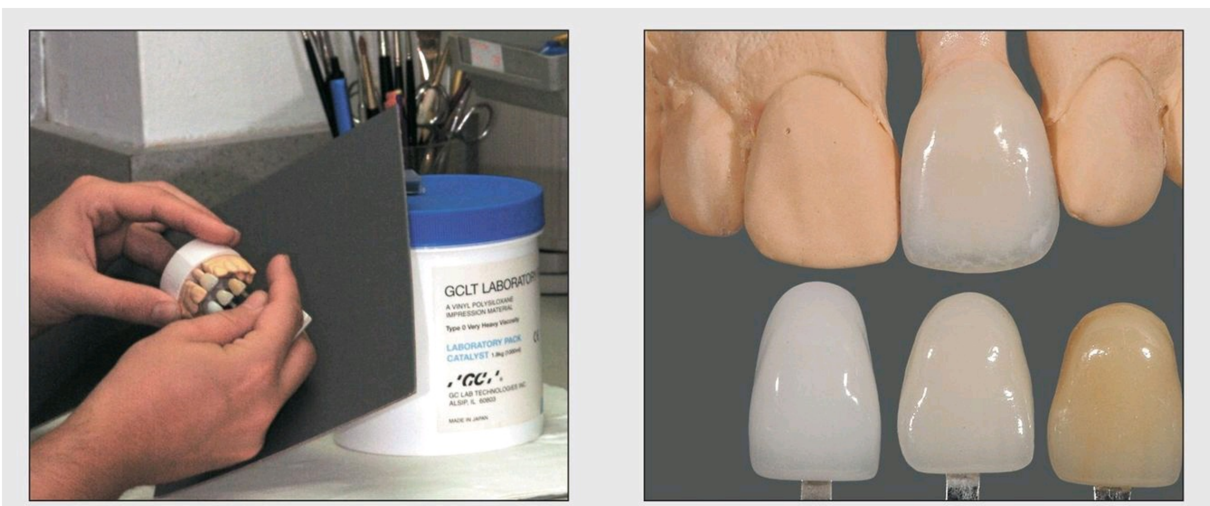
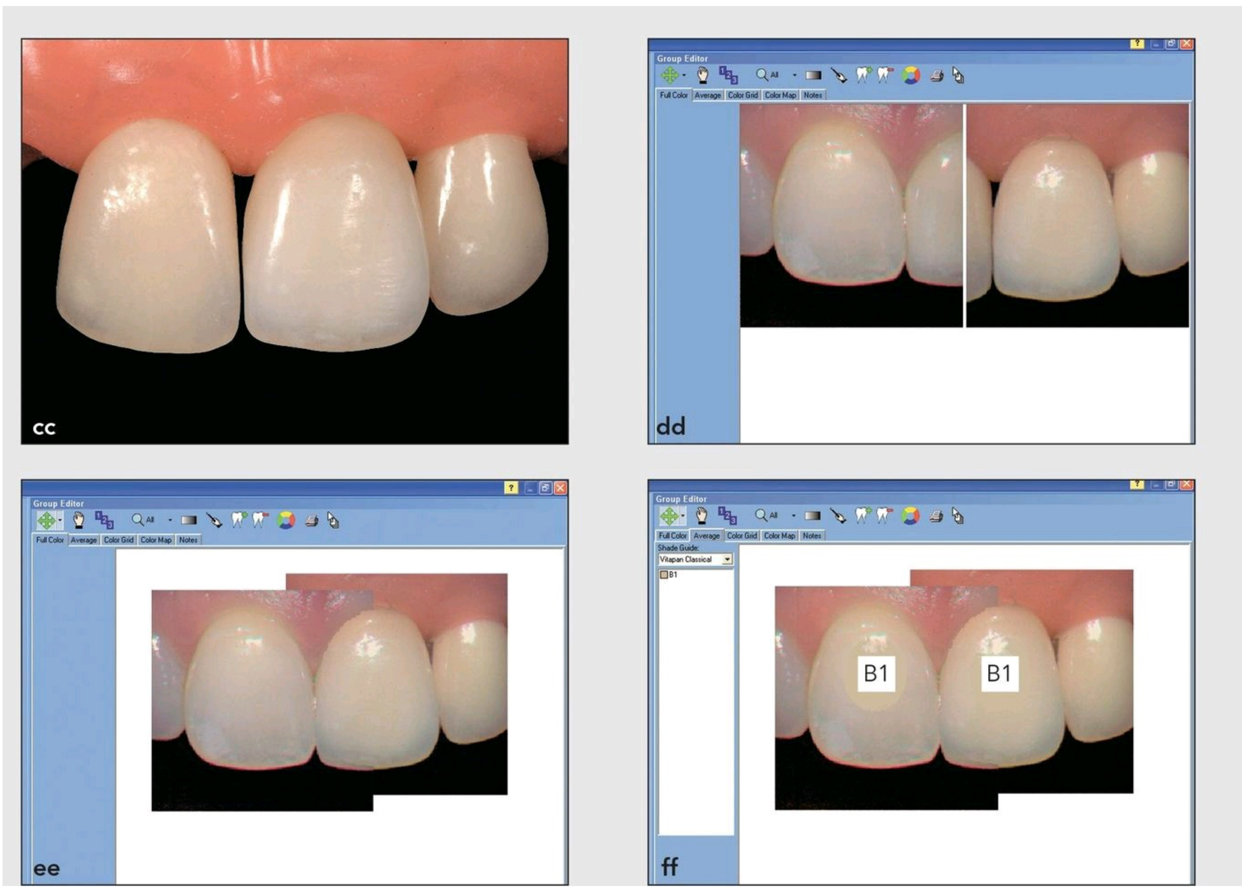


Fig 8-4z *(left) The extreme shade tabs used in the reference photographs are compared to the completed restoration against the 18% gray card. (right) Close-up of the extreme shade tabs being compared to the restoration.*

Figs 8-4aa and 8-4bb *Shades C1 (aa) and B1 (bb) (used in the reference photographs) are also compared to the completed restoration against the 18% gray card.*



Figs 8-4cc to 8-4ff *ShadeVision virtual try-in. (cc) The crown is placed in the restoration holder for scanning. (dd) Image of the natural right central incisor and scan of the crown for left central incisor. (ee) The virtual try-in confirms a visual match. (ff) The report verifies a base shade of B1.*

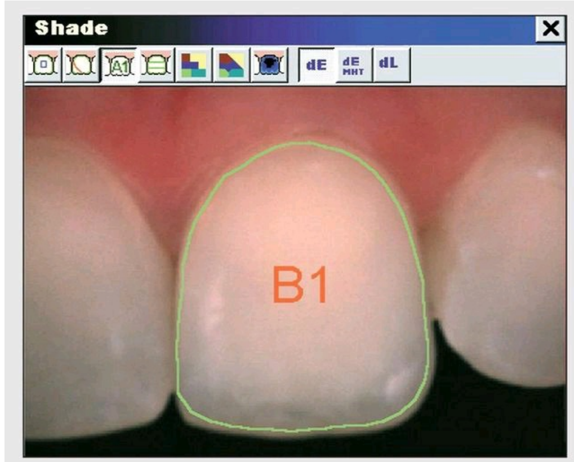


Fig 8-4gg *SpectroShade verification using spectrophotometric analysis. Shade B1 is again confirmed.*

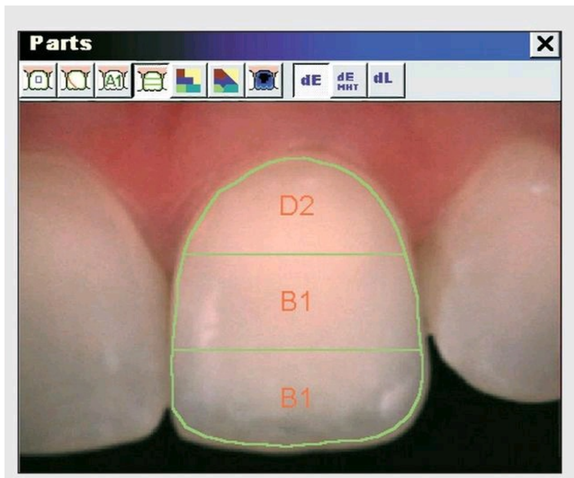


Fig 8-4hh *GBI shade distribution map verifies a close match, although there is a slight shade discrepancy at the gingival third (D2 versus C1 [see Fig 8-4e]). However, there is a very small ΔE* between shades C1 and D2.*

7. Placement

The ultimate verification of the accuracy of a restoration occurs when the clinician places the restoration (Figs 8-4ii to 8-4qq). If the restoration does not match, it will be immediately evident. Using this protocol (steps 1 to 6) should minimize if not eliminate the need for remakes at this clinical try-in stage. If, however, a remake or color adjustment is required, the analysis should be repeated and new reference photographs taken with the new restoration in place. Such problems are usually caused by errors in analysis, communication, or both.

Fig 8-4ii *The all-ceramic crown is prepared for cementation with composite resin cement (hydrofluoric acid etch, silane air dry, and bonding resin).*

Fig 8-4jj *The restoration is placed with a trial cement to visually verify the shade intraorally.*

Fig 8-4kk *Close-up intraoral view of cemented all-ceramic crown on the left central incisor.*

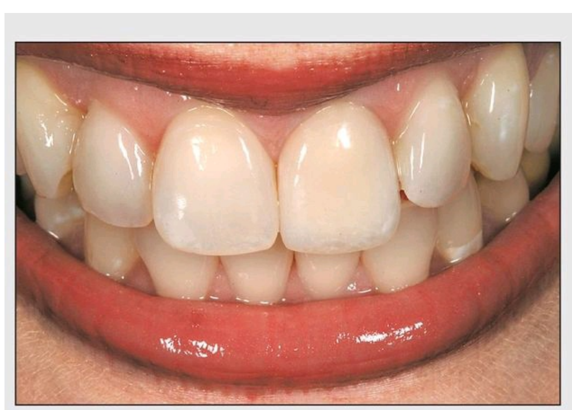
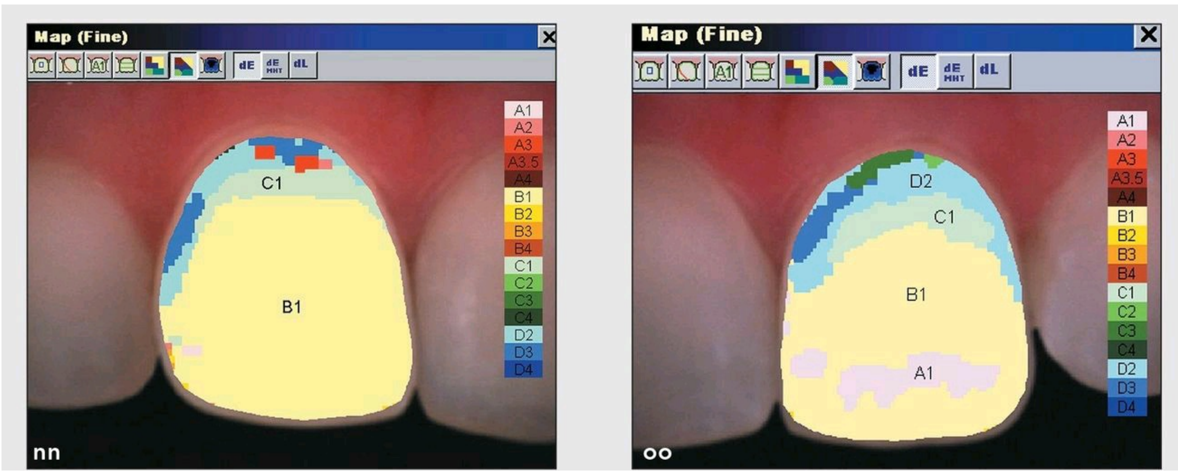


Fig 8-4ll *Close-up of smile with crown in place.*

Fig 8-4mm *Full view of smile.*



Figs 8-4nn and 8-4oo *Fine shade maps (SpectroShade) of the natural right central incisor (nn) and the all-ceramic crown on the left central incisor (oo). A close shade match is confirmed.*

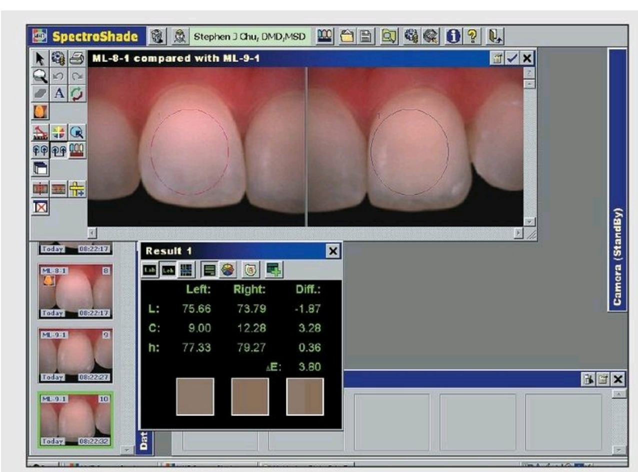


Fig 8-4pp *Total ΔE* of the natural right central incisor compared to the crown on the left central incisor is 3.80. The value ΔE* is–1.87. A ΔE* for value of less than 2.0 is highly clinically acceptable.*

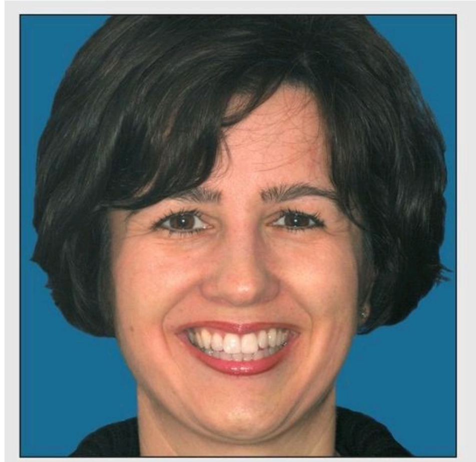


Fig 8-4qq *Full-face posttreatment clinical photograph. The patient is pleased with the final esthetic restorative outcome. With this recommended shade-taking protocol, challenging anterior restorations can be matched predictably with a clinically acceptable result in one visit.*

Summary

- Successful shade taking involves a combination of conventional and technology-based shade matching and reference photography.
- Details added by the lab technician in the fabrication process can often increase the natural appearance of a shade.
- Technology-based systems are extremely useful in the analysis and verification of a shade match.

References

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2. Devigus A. Die digitale Farbmessung in der Zahnmedizin. Quintessenz 2003;54:495–500.
3. Chu SJ, Trushkowsky RD, Paravina RD. Dental color matching instruments and systems. Review of clinical and research aspects. J Dent 2010;38 (suppl 2):e2–e16.

CHAPTER 9CLINICAL CASES

In this chapter:

Shade-matching protocols for:

- Single anterior implant-supported zirconia crown
- Single anterior ceramic laminate veneer using conventional shade technique
- Single anterior all-ceramic crown with a bleached tooth as the reference
- Single anterior all-ceramic crown with need for opacity control and complex characterizations
- Single anterior implant-supported metal-ceramic crown
- Single anterior ceramic laminate veneer
- Two anterior all-ceramic crowns
- Two anterior all-ceramic crowns with one anterior metal-ceramic crown
- Four anterior ceramic laminate veneers
- Single posterior all-ceramic crown
- Ten ceramic laminate veneers to match bleached teeth
- Two anterior direct composite restorations

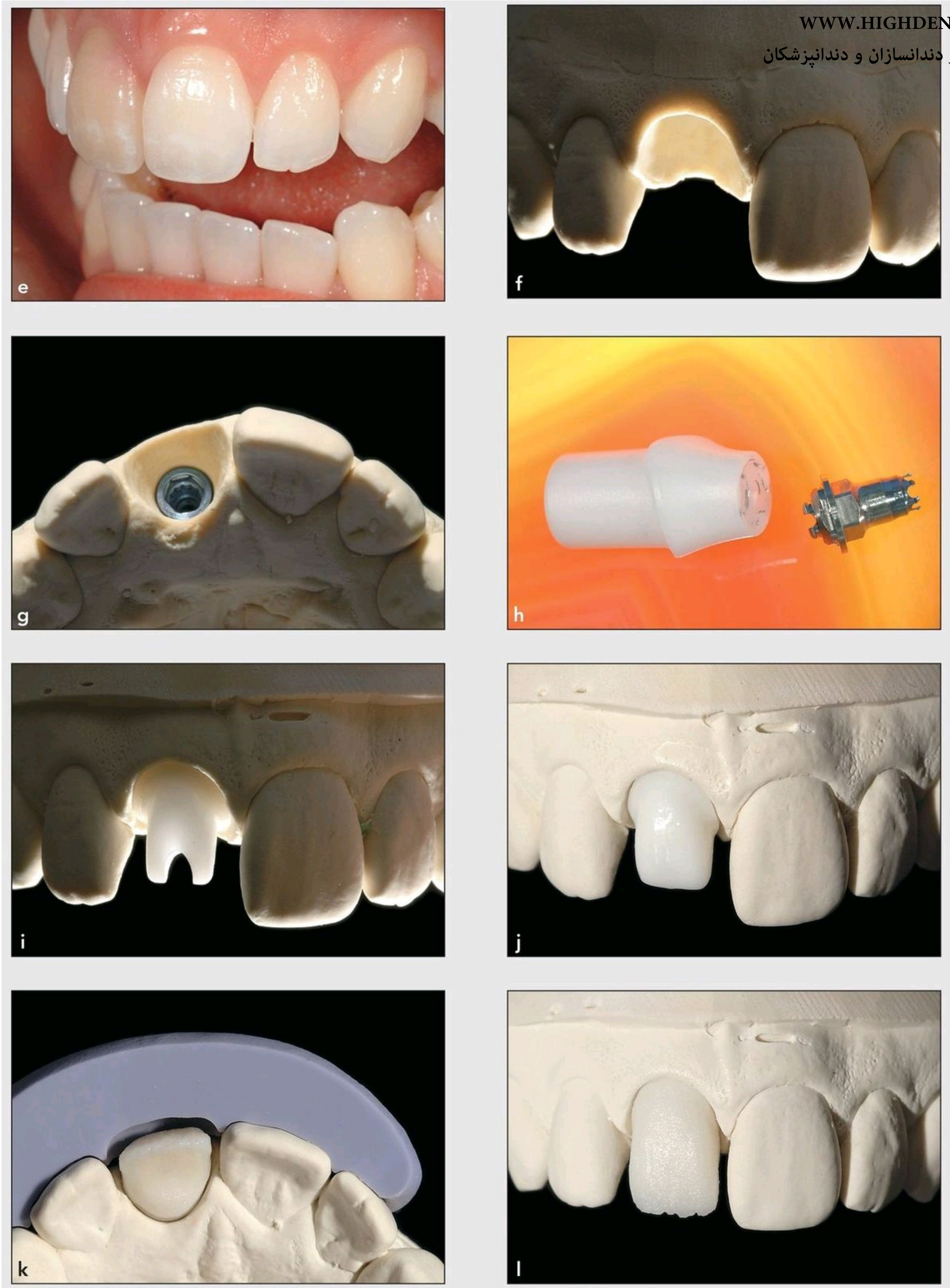
The following clinical cases demonstrate the use of the shade-matching protocol presented in chapter 8, ie, a combination of conventional and technology-based techniques. If this approach is followed, it is nearly assured that an accurate shade match will be achieved the first time, eliminating the need for any remakes.

Case 1: Single Anterior Implant-Supported Zirconia Crown

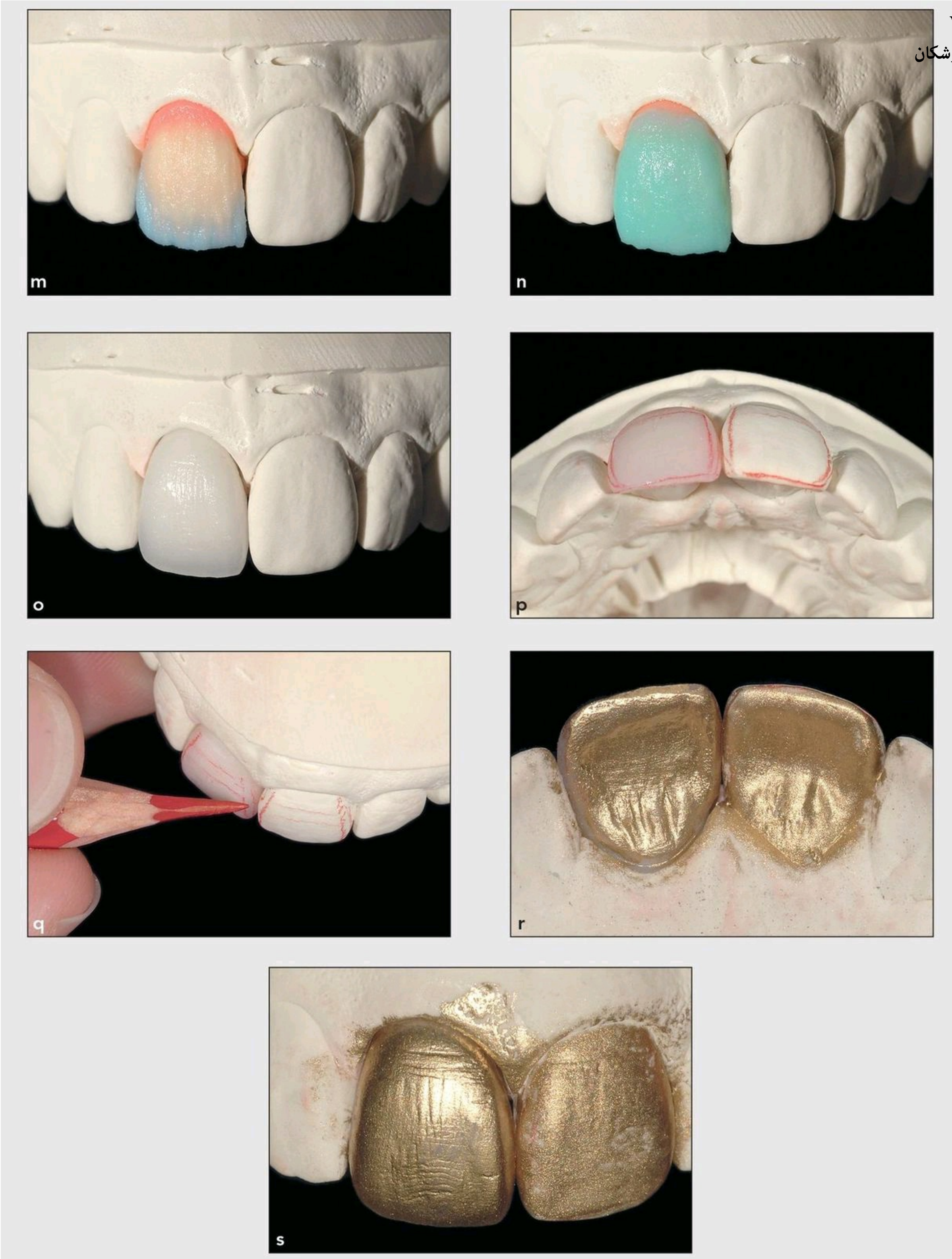
A 24-year-old woman presented with a dental history of external resorption of the maxillary right central incisor (Fig 9-1a). Conventional shade information with reference photography was collected at the preoperative appointment including base shade and value difference photographs (Figs 9-1b to 9-1d). Following atraumatic tooth removal, the selected implant (Nanotite [Biomet 3i]) was placed immediately into the extraction socket with an immediate provisional restoration (Fig 9-1e). A final implant-level impression was made, and a stone cast, which exactly replicated the intraoral placement of the implant, was fabricated in the laboratory (Figs 9-1f to 9-1i). An anatomical prefabricated zirconia implant abutment (Biomet 3i) was selected and modified in the laboratory using ceramic shoulder porcelain (HeraCeram [Heraeus-Kulzer]) (Figs 9-1j and 9-1k). The composite photography images, compiled using shade information and patient clinical images, were used to fabricate a zirconia crown for the maxillary right central incisor (Fig 9-1l). A zirconia coping was waxed, scanned, and finished, and a fluorescent bonding agent was applied to the surface (Figs 9-1m and 9-1n). The appropriate ceramic materials were layered (Fig 9-1o) and fired to maturation. Surface texture was created and verified using gold powder (Figs 9-1p to 9-1s), and the restoration was glazed and polished (Figs 9-1t to 9-1y). A successful esthetic result was achieved with a try-in shade visit and final insertion appointment, using the recommended conventional shade-matching protocol (Fig 9-1z).

Figs 9-1a to 9-1d

Figs 9-1e to 9-1l



Figs 9-1m to 9-1s

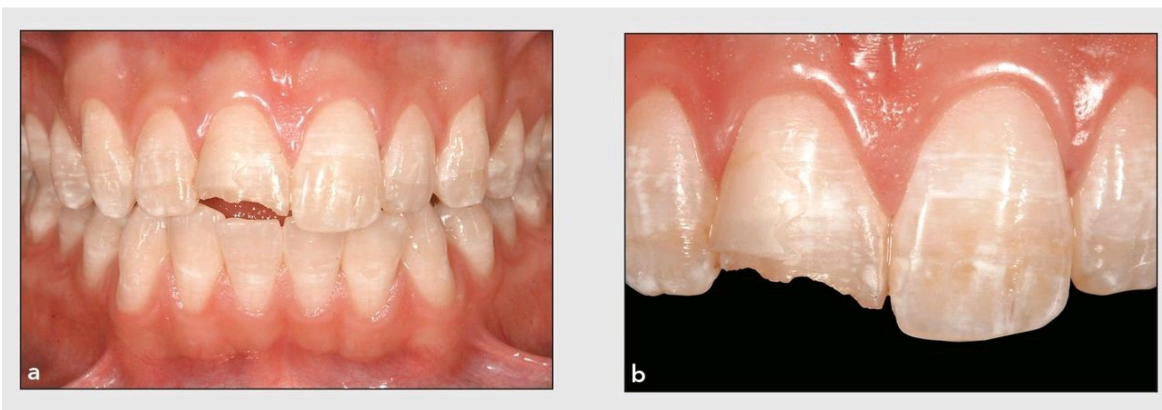


Figs 9-1t to 9-1z

Case 2: Single Anterior Ceramic Laminate Veneer Using Conventional Shade Technique

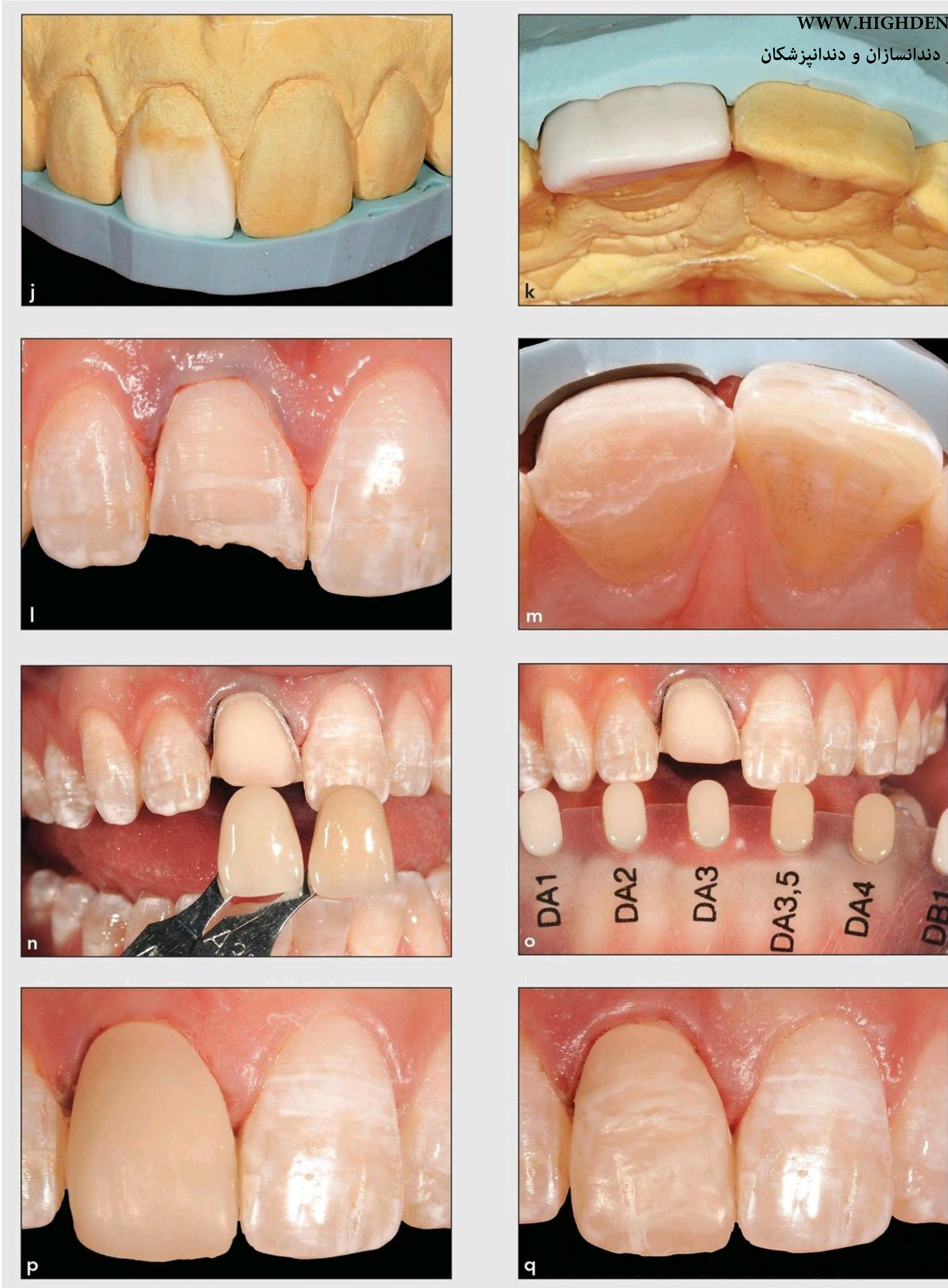
A 22-year-old man presented with a fracture of the labioincisal aspect of the maxillary right central incisor as a result of a traumatic accident (Figs 9-2a and 9-2b). Clinical examination revealed that the fractured portion of the tooth was an existing composite restoration (Figs 9-2c and 9-2d). The patient had a thin periodontal phenotype and tapered tooth morphology with a high smile line. Conventional shade analysis with reference digital photography was performed prior to treatment using laboratory shade tabs and porcelain powders (HeraCeram) (Figs 9-2e to 9-2g). A diagnostic wax-up of the restorative correction was fabricated (Figs 9-2h and 9-2i) and silicone indices (Flexitime Putty [Heraeus Kulzer]) were made to guide the labial and incisal tooth reduction for the veneer restoration (Figs 9-2j and 9-2k). The tooth was prepared using depth-cutting burs (Brasseler) (Fig 9-2l), and the reduction was verified using the silicone indices (Fig 9-2m). The stump, or prepared tooth, shade was taken with reference shade tabs (Vita Classical [Vita Zahnfabrik]) and photography (Figs 9-2n and 9-2o). A bis-acrylic provisional restoration (Luxatemp [DMG]) was made and custom-characterized using white ceramic stain powder mixed with unfilled light-cured resin and cemented with a noneugenol-based provisional cement (Tempbond NE [Kerr]) (Figs 9-2p and 9-2q). After the final impression was taken, a refractory cast was made (G-Cera Vest [GC America]) in the laboratory, and ceramic layering was performed for the construction of the veneer restoration (Figs 9-2r to 9-2z). The restoration was then evaluated for correct translucency and light transmission (Figs 9-2aa and 9-2bb). The definitive veneer restoration was finished, polished, etched, seated, and cemented (Figs 9-2cc and 9-2dd) with clear shade, light-cured resin cement (Variolink [Ivoclar-Vivadent]). A highly esthetic outcome was achieved (Figs 9-2ee and 9-2ff) with this shade technique and verified intraorally with a spectrophotometric-based shade instrument (Figs 9-2gg and 9-2hh).

Figs 9-2a and 9-2b

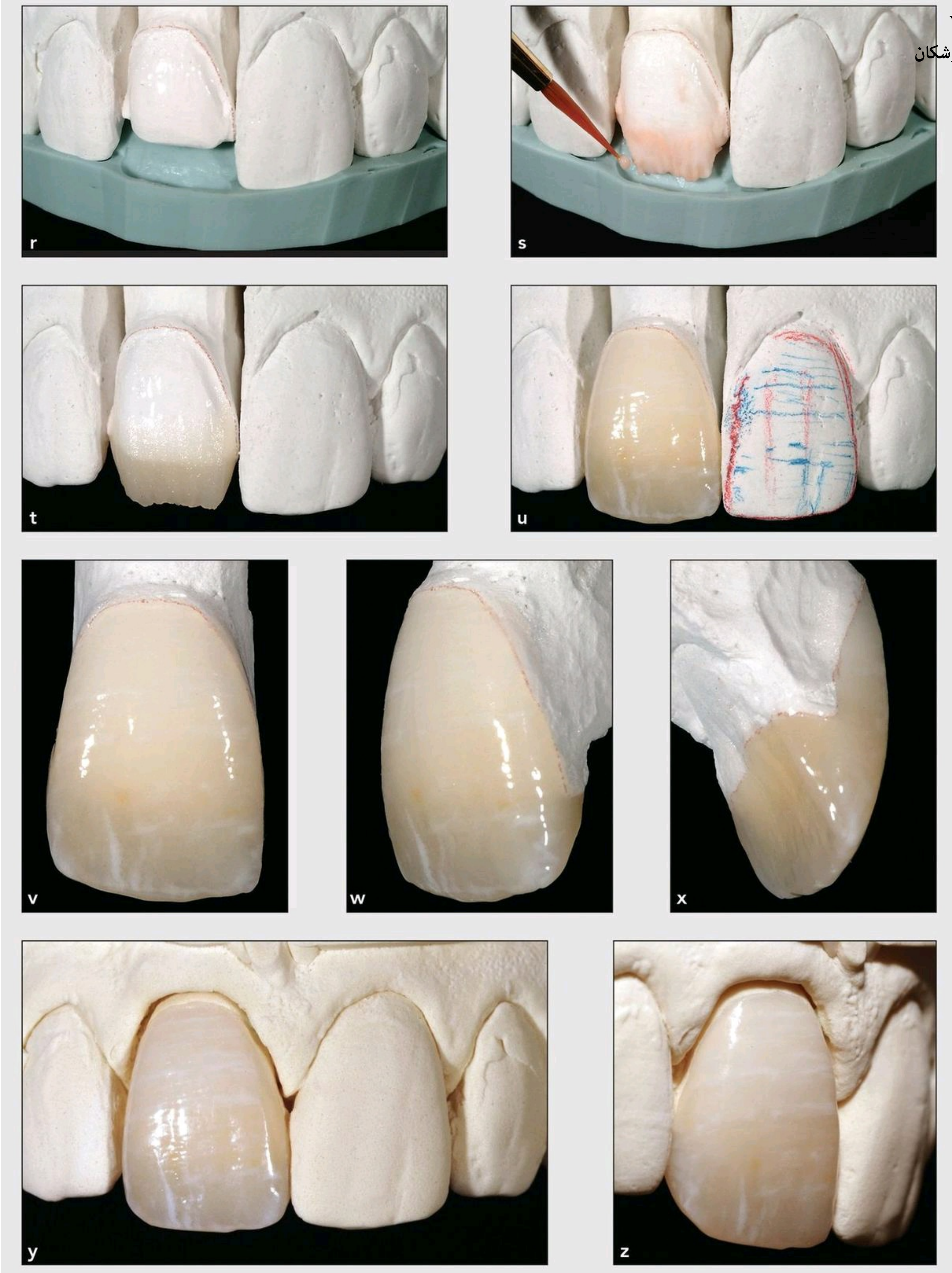


Figs 9-2c to 9-2i

Figs 9-2j to 9-2q



Figs 9-2r to 9-2z



Figs 9-2aa to 9-2hh

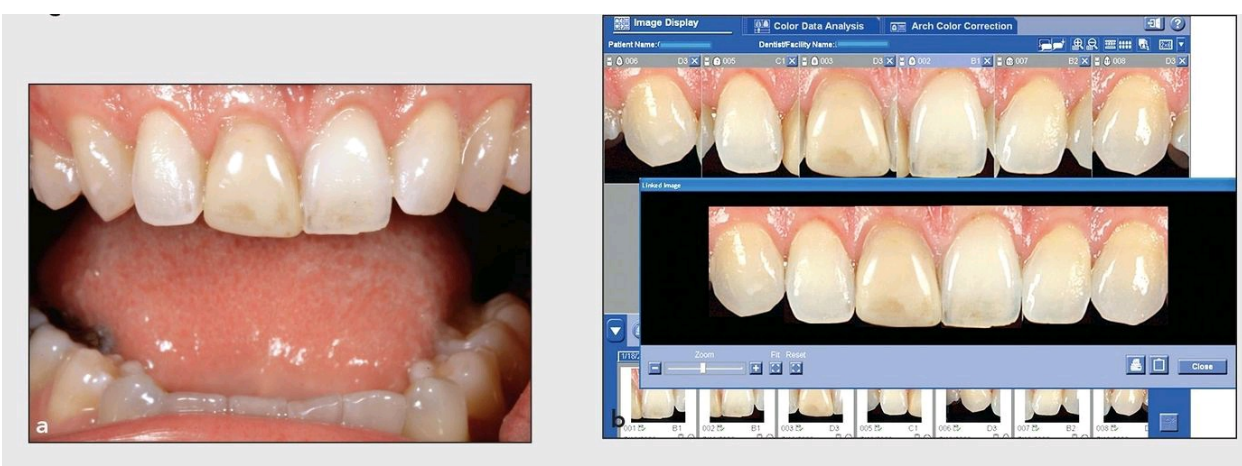
Case 3: Single Anterior All-Ceramic Crown with a Bleached Tooth As the Reference

A 36-year-old man needed an all-ceramic crown for his maxillary right central incisor (Fig 9-3a). A dental spectrophotometer (Crystaleye [Olympus]) was used for the color management, and spectral images of six maxillary anterior teeth were captured on the first visit (Fig 9-3b). The patient desired to have his teeth bleached as well. In-office bleaching was performed and was followed with at-home tray bleaching for 1 week to stabilize the color change. Spectral images of the teeth and arch were captured prior to bleaching and after bleaching (Fig 9-3c), and color measurements and color analysis were performed. Tooth color measurements indicated significant changes, specifically a higher L* (value) and lower b* (yellowness) (Fig 9-3d). Color management software provided a color simulation based on spectral data, which was helpful in simulating potential color change prior to bleaching (Fig 9-3e).

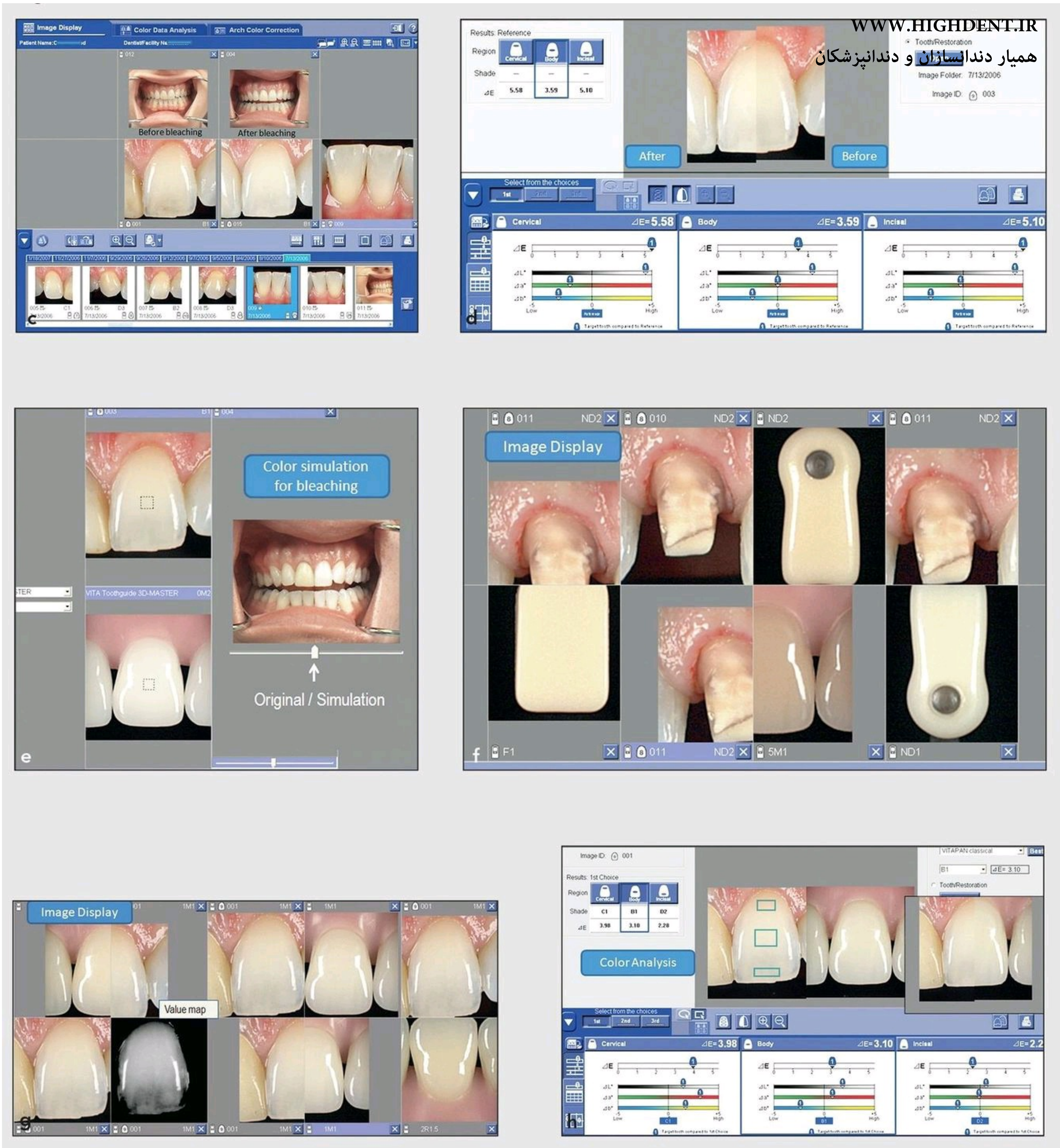
A custom-cast post and core with porcelain coverage was cemented with composite luting cement (RelyX ARC [3M ESPE]), and a final impression was taken with a polyether impression material (Impregum [3M ESPE]) 6 weeks after tray bleaching was completed.

In order to create an accurate definitive restoration color, the abutment color must to be taken into consideration. In this case the prepared tooth with a post and core had significant color variation from the cervical to the incisal area. The cervical area was a relatively dark shade. This contrasted with the body area, which was a lighter shade (Fig 9-3f). The die material was carefully selected based on the color assessment. In the image display mode, the target, or reference, shade of the crown (on the maxillary left central incisor) was compared with shade guides. Overall, this crown was light with translucency from the body to the incisal area and had value gradation with depth as well (Fig 9-3g). The color analysis showed that the closest shade match in the body area was Vita Classical B1, Vita 3D-Master 1M-1, and Noritake B1 (Fig 9-3h). However, no shade guide had a color match below the 50:50% perceptibility threshold (color difference ΔE* ≈ 1.5 to 2.0). Based on the color analysis with L*a*b* indices, the technician created a porcelain blue map to reproduce the color (Fig 9-3i). In the body area, Noritake B1 was used as a base shade and NW0 (*Neutral White*), which is lighter than Noritake B1, was also used to increase the value. The first bake virtual try-in provided important color information for the final porcelain layering (Fig 9-3j). Both the cervical and the incisal areas needed increased chroma (yellow component) and the cervical area required higher value. In contrast, the body area needed just a slight increase in value. The definitive restoration had excellent esthetics and anatomy (Figs 9-3k and 9-3l). The overall color difference (ΔE*) was less than 1.5, which is well below the 50:50% perceptibility threshold. *Clinical procedure performed by Aki Yoshida, RDT, and Dr Lloyd Miller.*

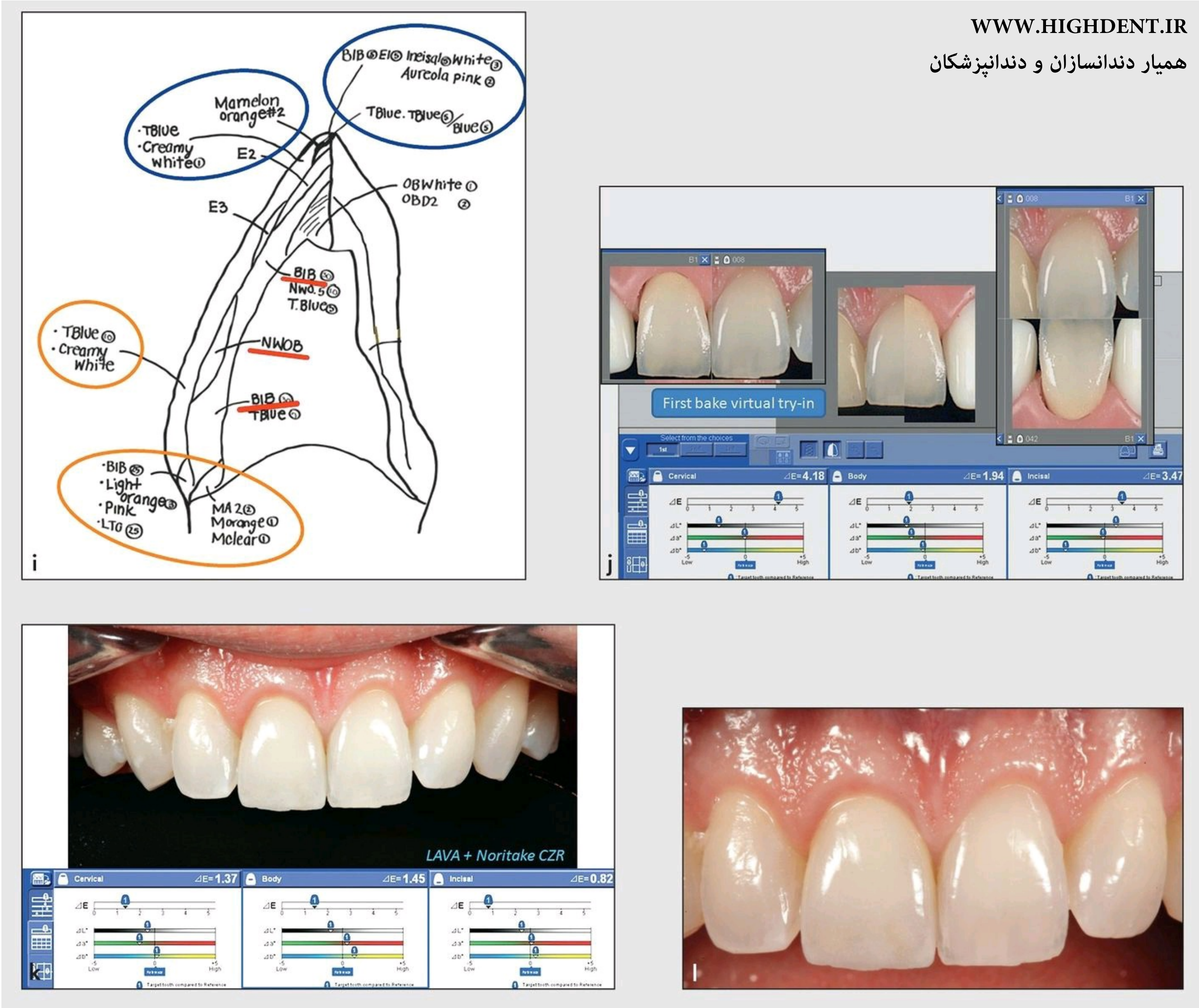
Figs 9-3a and 9-3b



Figs 9-3c to 9-3h



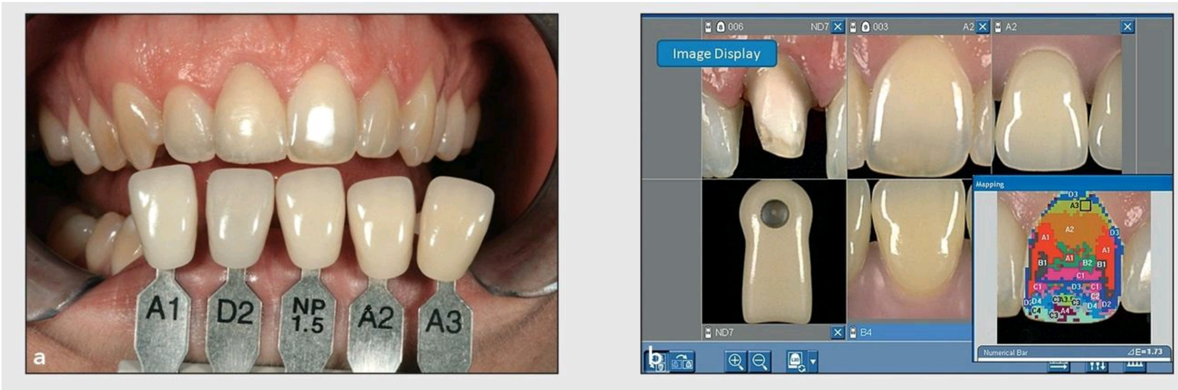
Figs 9-3i to 9-3l



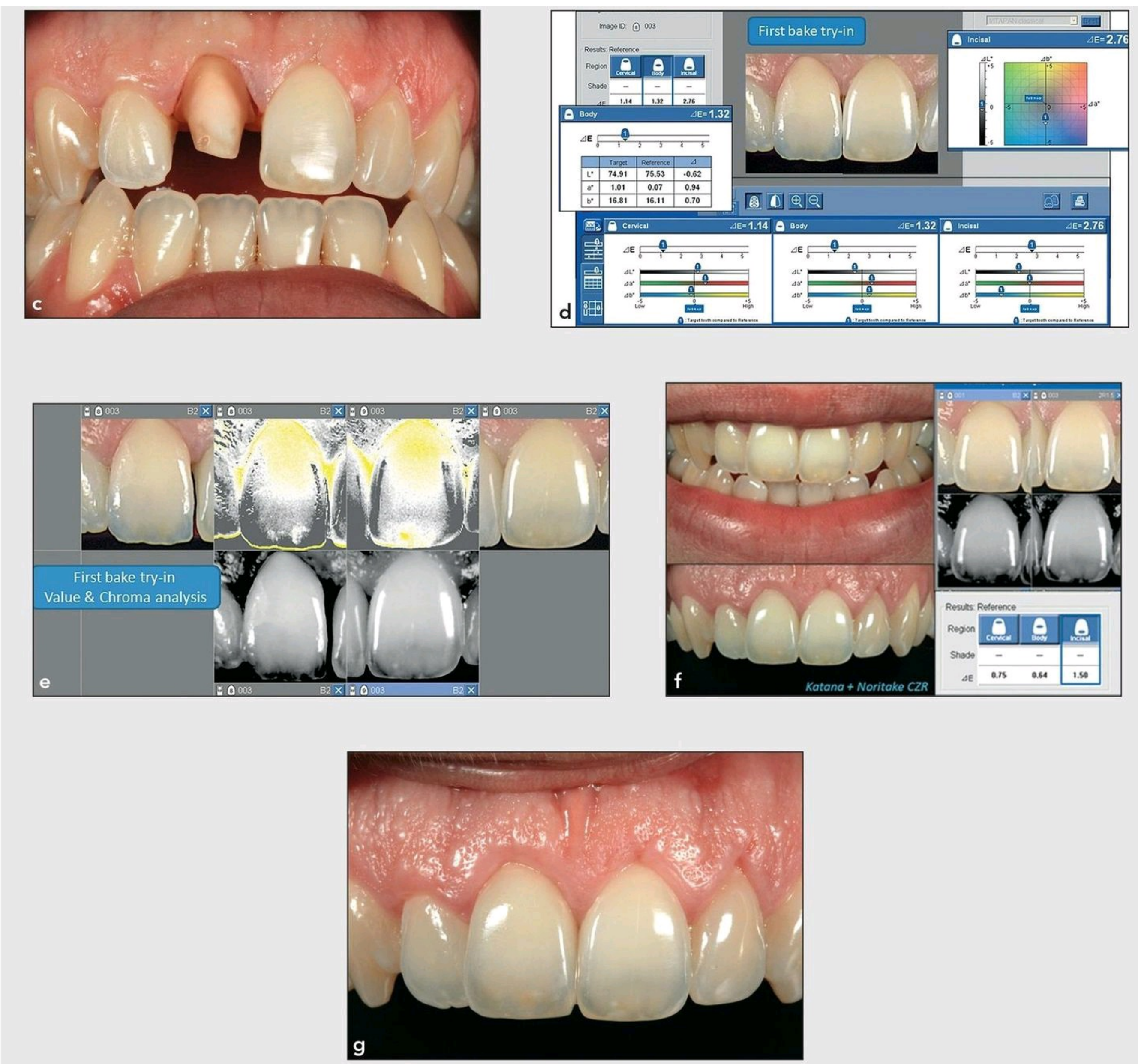
Case 4: Single Anterior All-Ceramic Crown with Need for Opacity Control and Complex Characterizations

A 29-year-old woman desired a new crown for the maxillary right central incisor. The patient did not like the texture and opacity of her current crown compared to the adjacent natural teeth (Fig 9-4a). First, the colors of the target tooth (maxillary left central incisor) and the prepared tooth (maxillary right central incisor) were carefully analyzed and mapped (Fig 9-4b). The target tooth had multiple shades and complex characteristics, including a highly translucent incisal area. The cervical portion of the prepared tooth was a dark shade. The color reproduction began with opacity control of the ceramic core (Fig 9-4c). An equal combination of shade base powder and opacious body porcelain was applied to the zirconia ceramic core (Katana [Noritake]; shade NT11) to mask the underlying dark color of the prepared tooth. The A1 shade (Noritake CZR) was used as a base shade, and the internal live stain technique was applied to create complex characterization while maintaining high translucency from the body to the incisal area. After the initial bake, the crown was placed on the abutment with a glycerin try-in paste, and the color was measured (Figs 9-4d and 9-4e). After the first bake, the try-in ΔEs* were 1.14 and 1.32 in the cervical and body areas, respectively. These ΔE*s are considered to be in the range of an ideal color match; therefore, a neutral color porcelain (LT1; Luster Translucent [Noritake]) was used to avoid altering the color. The definitive restoration had a superior luster, texture, and color match (Figs 9-4f and 9-4g). The ΔE*s for each tooth section were less than 1.0, and characteristics in the incisal area were reproduced naturally. *Clinical procedure* performed by Aki Yoshida, RDT.

Figs 9-4a and 9-4b



Figs 9-4c to 9-4g

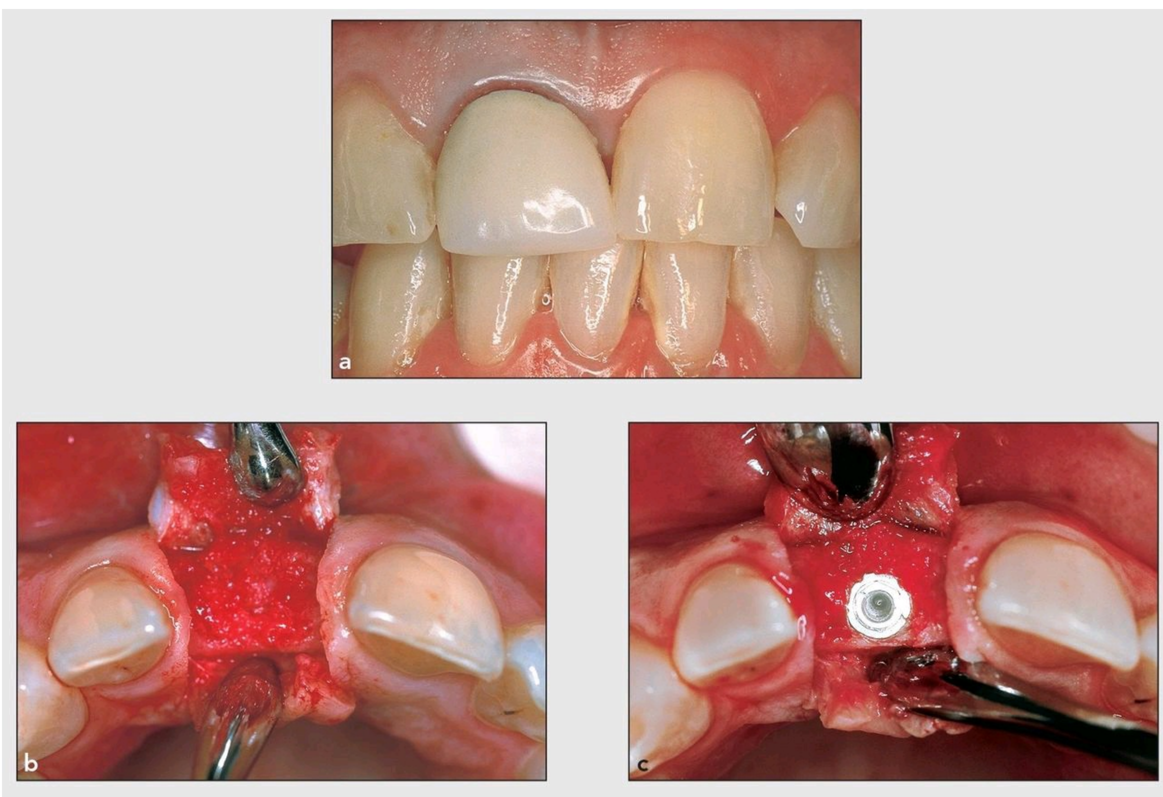


Case 5: Single Anterior Implant-Supported Metal-Ceramic Crown

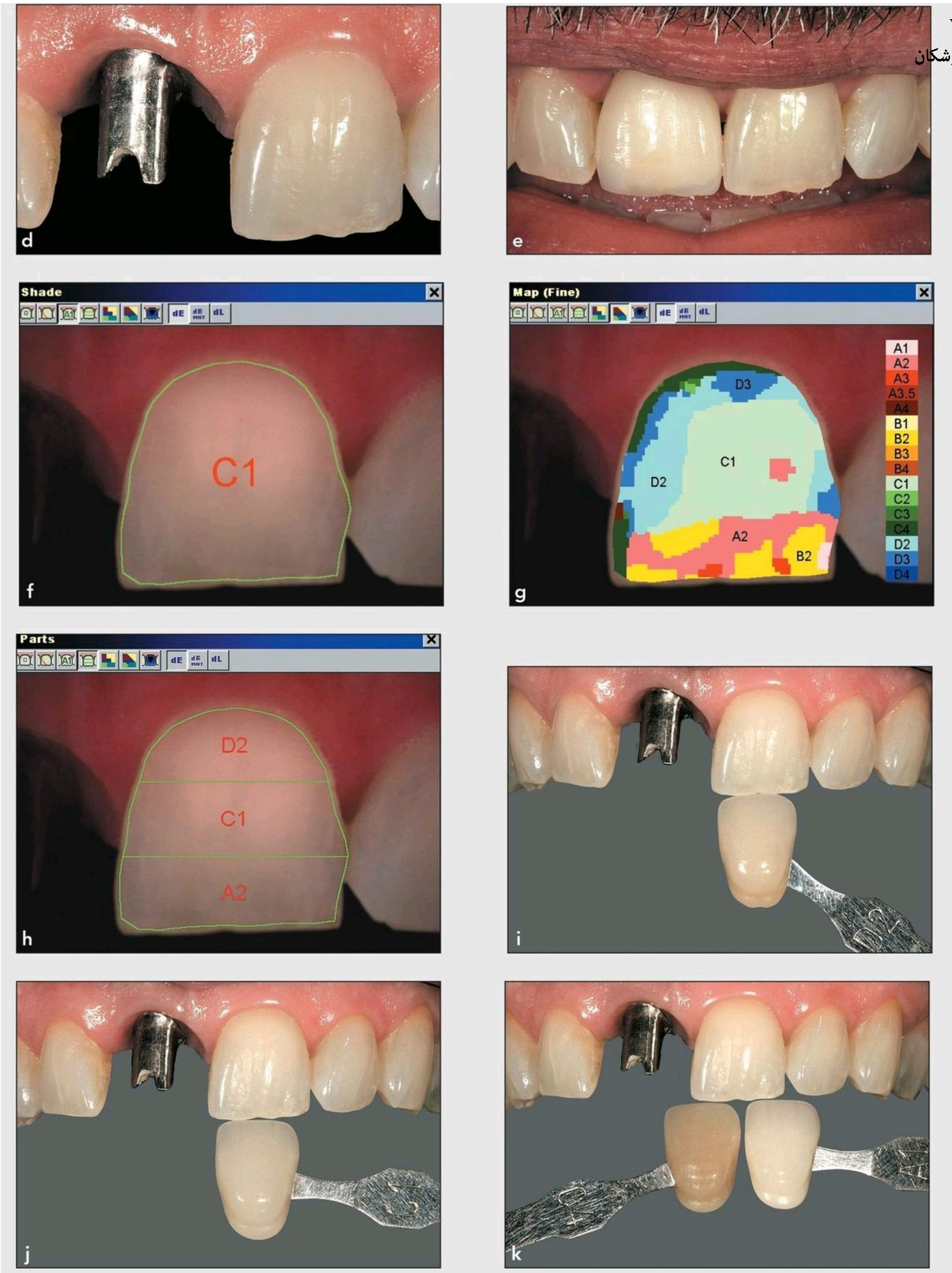
A 54-year-old man presented with a dental history of failing root canal treatment on the maxillary right central incisor (Fig 9-5a). A bone allograft (Puros [Zimmer]) was placed (Fig 9-5b) following atraumatic surgical removal, and a selected surface implant (Osseotite [Biomet 3i]) was placed 6 months after socket maturation (Fig 9-5c). A custom implant abutment was inserted (Fig 9-5d), and several metal-ceramic crowns were made for the right central incisor using only conventional shade determination with poor esthetic results (Fig 9-5e).

The recommended shade protocol, employing technology-based shade analysis (SpectroShade [MHT]) (Figs 9-5f to 9-5h) and reference photographs for color communication and value assessment (Figs 9-5i to 9-5k), was then used to fabricate a new metal-ceramic crown. A metal alloy coping was waxed, cast, and finished, and opaque porcelain was applied (Fig 9-5l). The appropriate ceramic materials were layered (Fig 9-5m) and fired to maturation. Surface texture was verified using gold powder (Fig 9-5n), and the restoration was glazed and polished (Fig 9-5o). The final comparative SpectroShade analysis showed an overall ΔE* of 3.65 and a ΔL (value) of less than 2.0 (Fig 9-5p). The value parameter is the most significant because the human eye can perceive differences in the lightness and darkness of shades more easily than it can detect variations in hue. A successful esthetic result was achieved in one attempt using the recommended shade-matching protocol (Fig 9-5q). *Surgical and restorative portions of this case performed by Dr Dennis Tarnow and Dr Marion Brown, respectively.*

Figs 9-5a to 9-5c



Figs 9-5d to 9-5k



Figs 9-5l to 9-5q

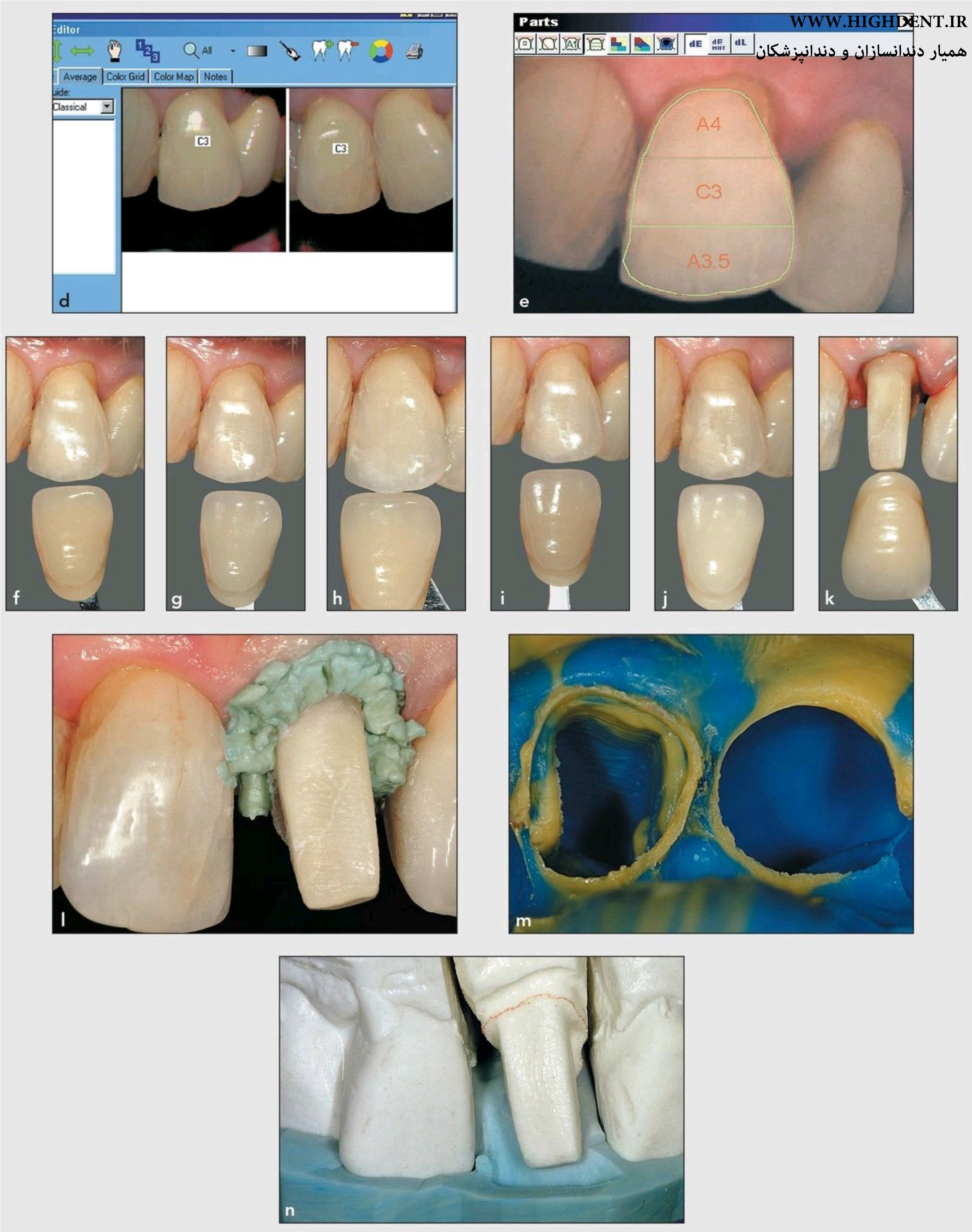
Case 6: Single Anterior Ceramic Laminate Veneer

A 79-year-old woman presented with significant interproximal mesial and distal decay on her maxillary left central incisor (Figs 9-6a and 9-6b). Because of the high translucency of the tooth to be matched, a ceramic laminate veneer was the restoration of choice. ShadeScan (Cynovad) (Fig 9-6c), ShadeVision (X-Rite) (Fig 9-6d), and SpectroShade (MHT) (Fig 9-6e) were used for shade analysis of the reference tooth. Vitapan A4 (Fig 9-6f), C3 (Fig 9-6g), and A3.5 (Fig 9-6h) shade tabs were used in the reference photographs based on the SpectroShade GBI map (see Fig 9-6e). In addition, reference photographs of extreme shade tabs were taken for value determination; a Vitapan C4 tab was selected for the dark reference (Fig 9-6i) and an A2 for the light reference (Fig 9-6j).

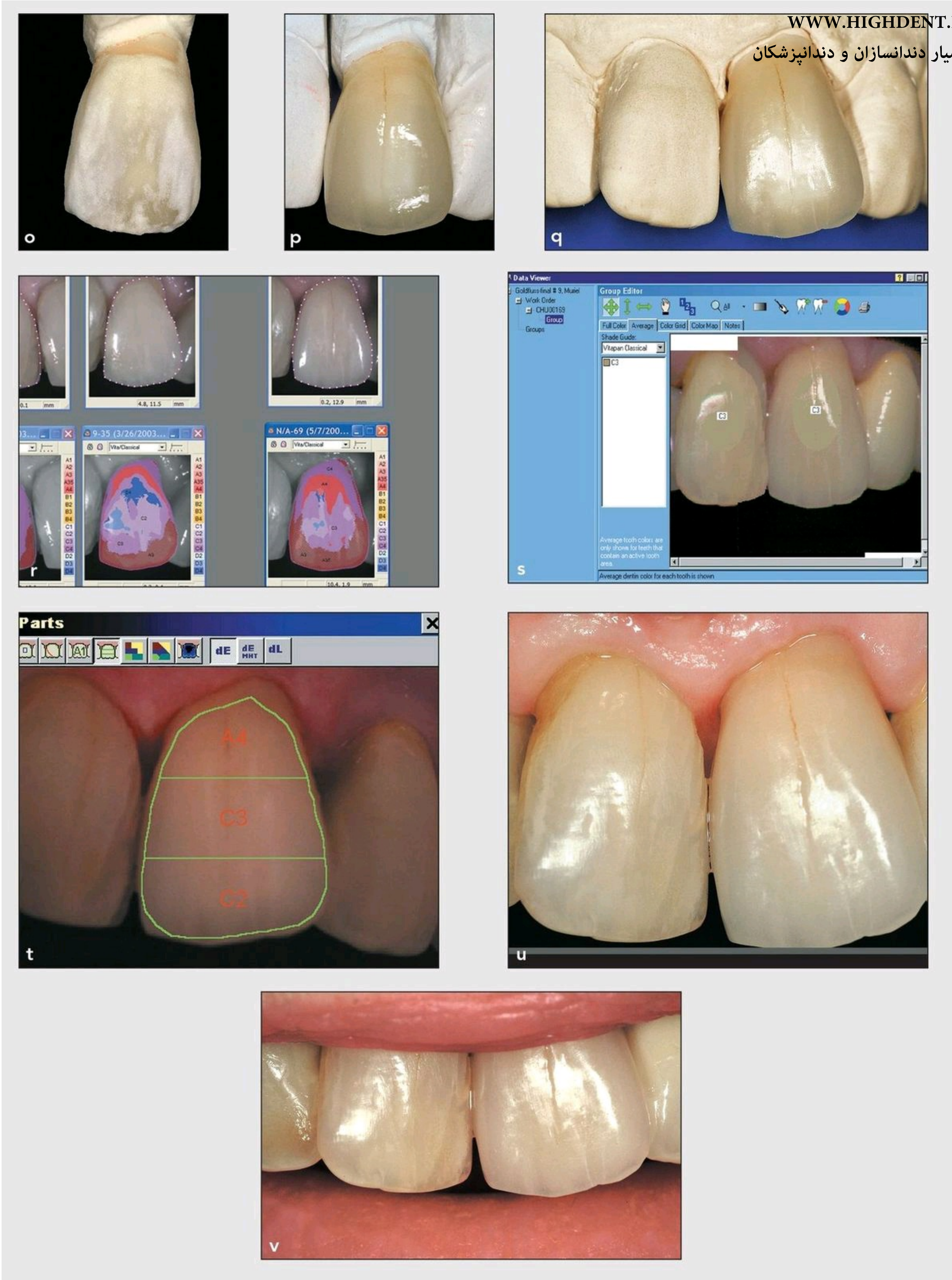
Mesial and distal decay were removed, and the shade of the remaining natural tooth material was determined to be A3.5 (Fig 9-6k). A paste deflection tissue management system (Expasyl [Kerr]) was used to control crevicular fluids and expose the apical extent of the preparation margin (Fig 9-6l) prior to final impression taking with a polyvinyl siloxane material (Honigum [Zenith/DMG]) (Fig 9-6m). A gypsum cast was poured and duplicated for a refractory cast (Fig 9-6n). An incisal addition silicone index was used during the dentin ceramic buildup to establish the incisal edge position of the restoration. Special effects ceramic materials were layered (Fig 9-6o) prior to final firing and glazing to establish proper surface luster (Fig 9-6p); note the translucency of the synthetic ceramic material (HeraCeram), as evidenced by the visibility of the prepared die through the restoration. The restoration was polished to achieve the final luster. After divestment, the veneer was fitted to the solid cast to establish proper proximal contacts and soft tissue emergence profile (Fig 9-6q). Using the recommended shade protocol, a predictable and acceptable esthetic result was achieved with the fabrication of one restoration. The successful shade match was verified by ShadeScan before and after images (Fig 9-6r), the ShadeVision virtual try-in (Fig 9-6s), and the SpectroShade GBI map (Fig 9-6t), as well as by the final clinical photographs (Figs 9-6u and 9-6v).

Figs 9-6a to 9-6c

Figs 9-6d to 9-6n



Figs 9-6o to 9-6v

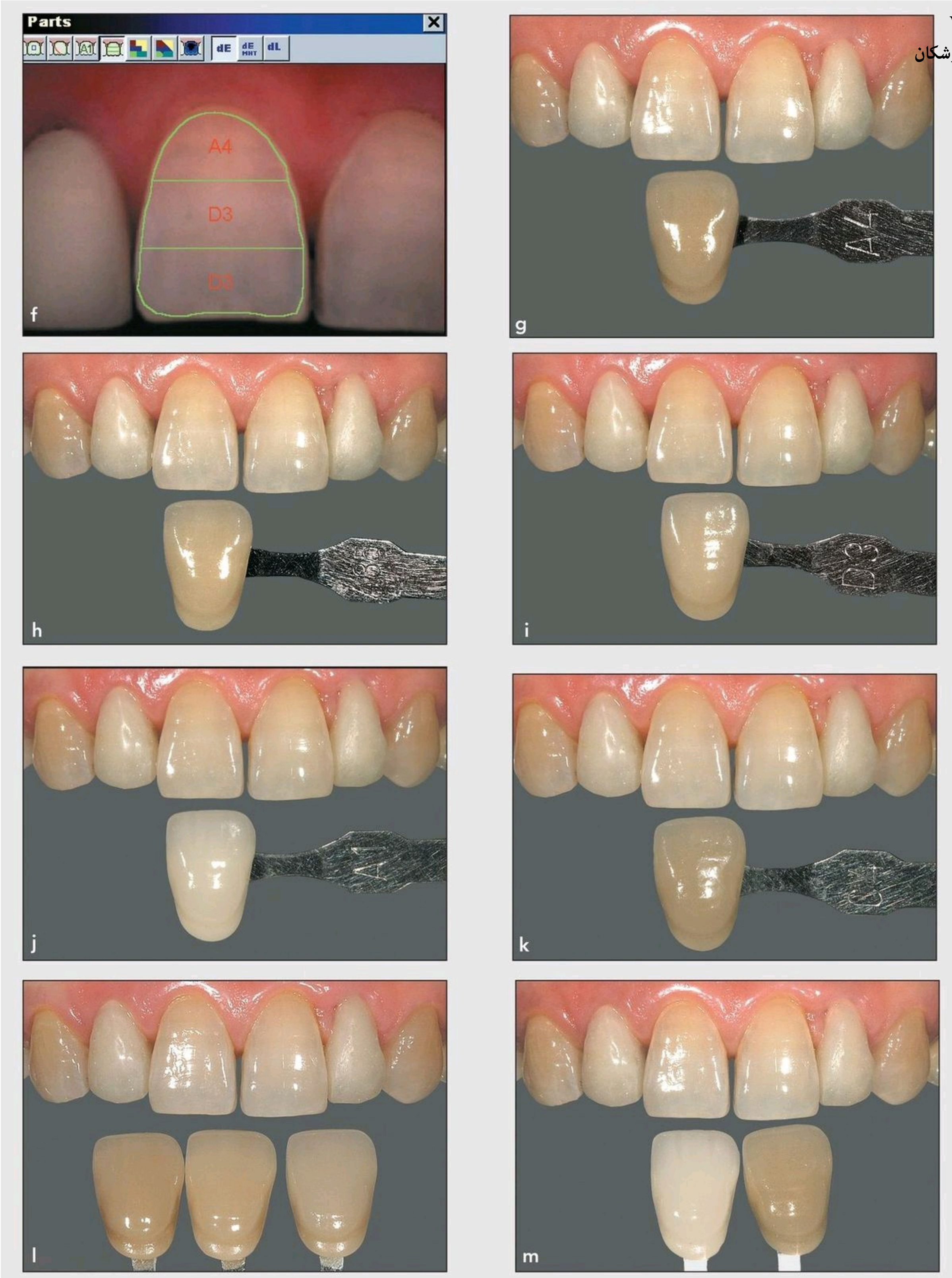


Case 7: Two Anterior All-Ceramic Crowns

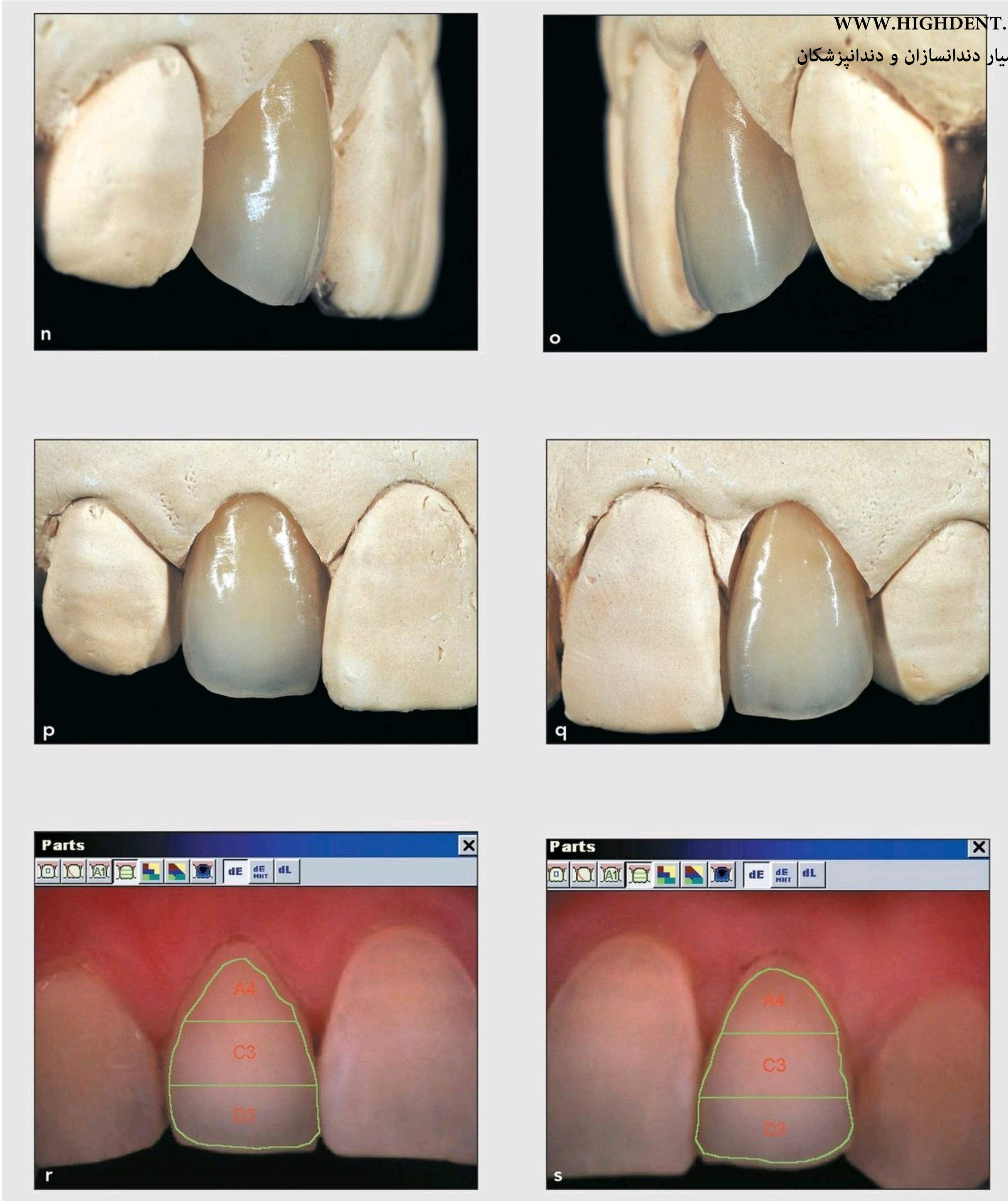
A 57-year-old woman presented with two maxillary lateral incisor crowns that did not match in shade and were causing gingival irritation due to poor emergence profile contours (Figs 9-7a to 9-7c). Provisional restorations were made to allow the gingival tissues to heal. Close-up photographs of the central incisors were taken from different angles to communicate shade variations to the lab technician (Figs 9-7d and 9-7e). A SpectroShade GBI map was generated (Fig 9-7f), based upon which reference photographs of shade tabs were taken (Figs 9-7g to 9-7l). A reference photograph with the extreme shade tabs was also captured to assess value and chroma (Fig 9-7m). The all-ceramic crowns (HeraCeram) were fabricated in the laboratory, and the shade was visually verified. The proper embrasure and emergence profiles of the restorations were confirmed on the solid cast (Figs 9-7n to 9-7q). Once the restorations were placed, the successful shade match was confirmed by the SpectroShade GBI maps (Figs 9-7r and 9-7s) and clinical photographs (Figs 9-7t to 9-7v).

Figs 9-7a to 9-7e

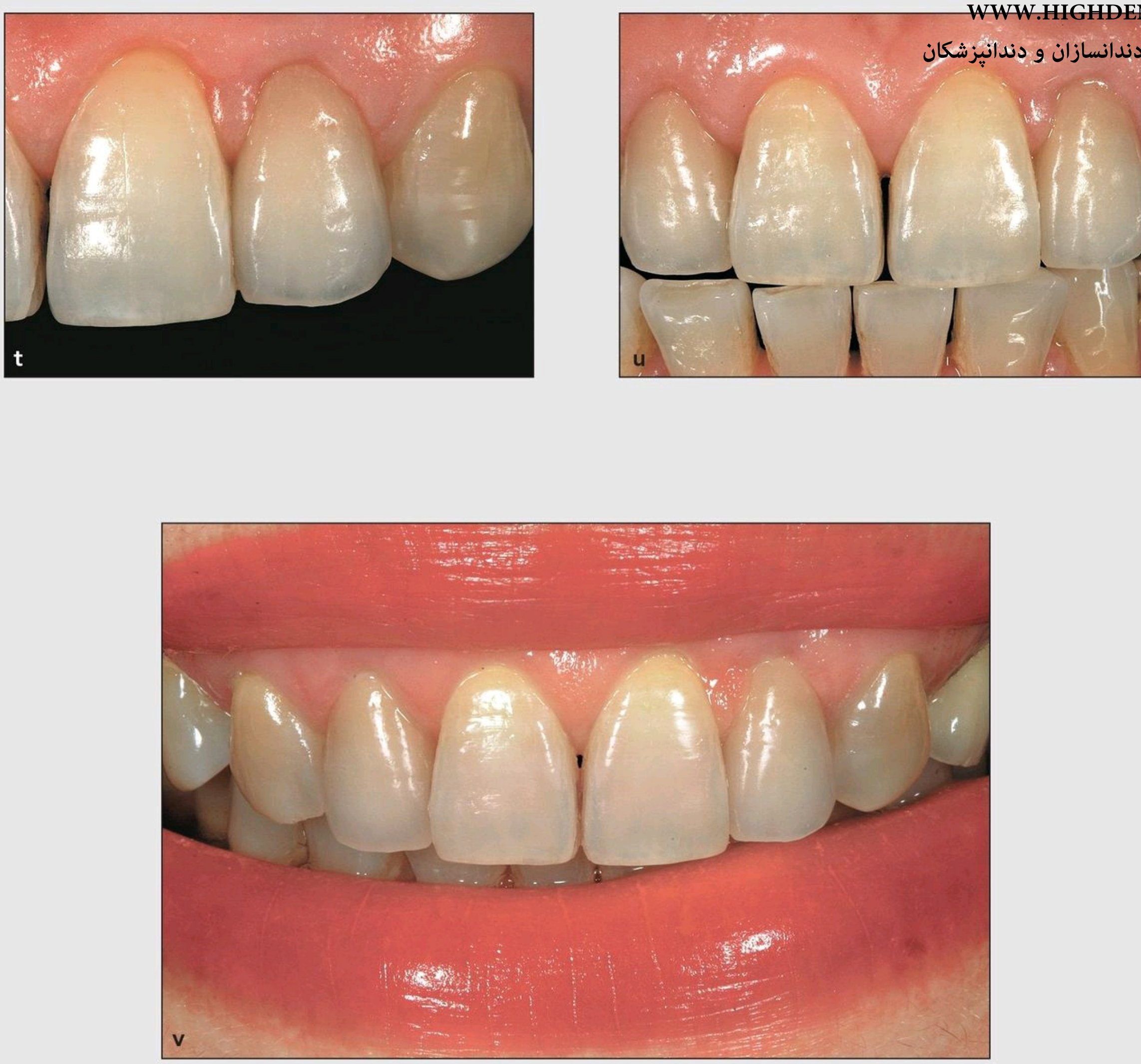
Figs 9-7f to 9-7m



***Figs 9-7n* to 9-7s**



Figs 9-7t to 9-7v

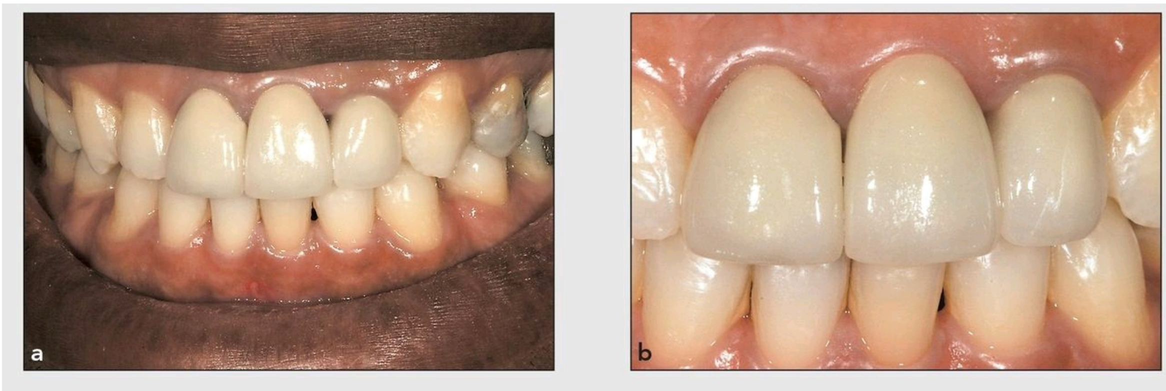


Case 8: Two Anterior All-Ceramic Crowns with One Anterior Metal-Ceramic Crown

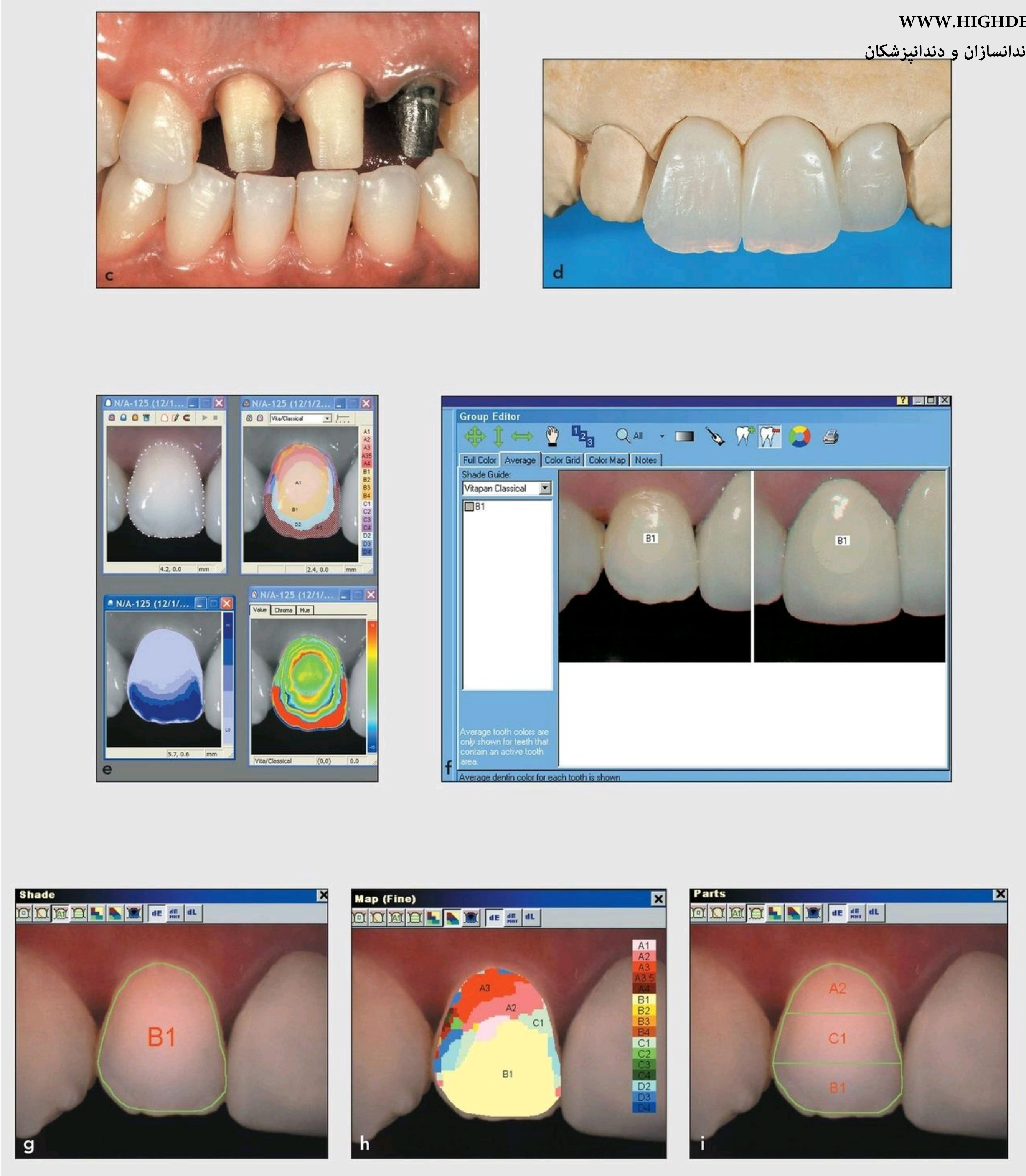
A 36-year-old man recently had received full-coverage crowns on his maxillary central incisors and left lateral incisor with an extremely dissatisfactory result (Figs 9-8a and 9-8b). Root canal therapy had been performed on both lateral incisors, with the left receiving an alloy post and core foundation restoration, which discolored the remaining tooth structure as a result of oxidation of the alloy post (Fig 9-8c). The right central incisor preparation was slightly more discolored than the left central incisor because of precipitation of ferric sulfide salts into the dentinal tubules following root canal therapy (see Fig 9-8c).

Provisional restorations were made to restore proper form, proportion, and incisal length and as a blueprint for the definitive restorations (Fig 9-8d). ShadeScan (Fig 9-8e), ShadeVision (Fig 9-8f), and SpectroShade (Figs 9-8g to 9-8i) were used to determine the shade of the natural dentition. Shade communication was performed using reference photographs with the shade tabs suggested by the technology-based shade analysis (Figs 9-8j to 9-8m), as well as extreme shade tabs for value and chroma assessment (Figs 9-8n and 9-8o). All-ceramic refractory crowns were selected for the central incisors, and an alloy-reinforced crown was selected for the left lateral incisor to mask the discolored preparation and root (Fig 9-8p). The restorations were baked and shaped, and proper surface texture and luster were created (Fig 9-8q). The restorations were evaluated for correct depth of incisal effects, translucency, and light transmission (eg, blue opalescence shown in Fig 9-8r). The ShadeVision virtual try-in visually verified accurate shade reproduction (Fig 9-8s). The SpectroShade compared synchronized images to establish an aggregate ΔE* value of less than 2.0, which confirmed a very close match (Fig 9-8t), as seen in the clinical photographs of the definitive restorations (Figs 9-8u and 9-8v). The use of different restorative materials was integral to achieving the desired esthetic result.

Figs 9-8a and 9-8b

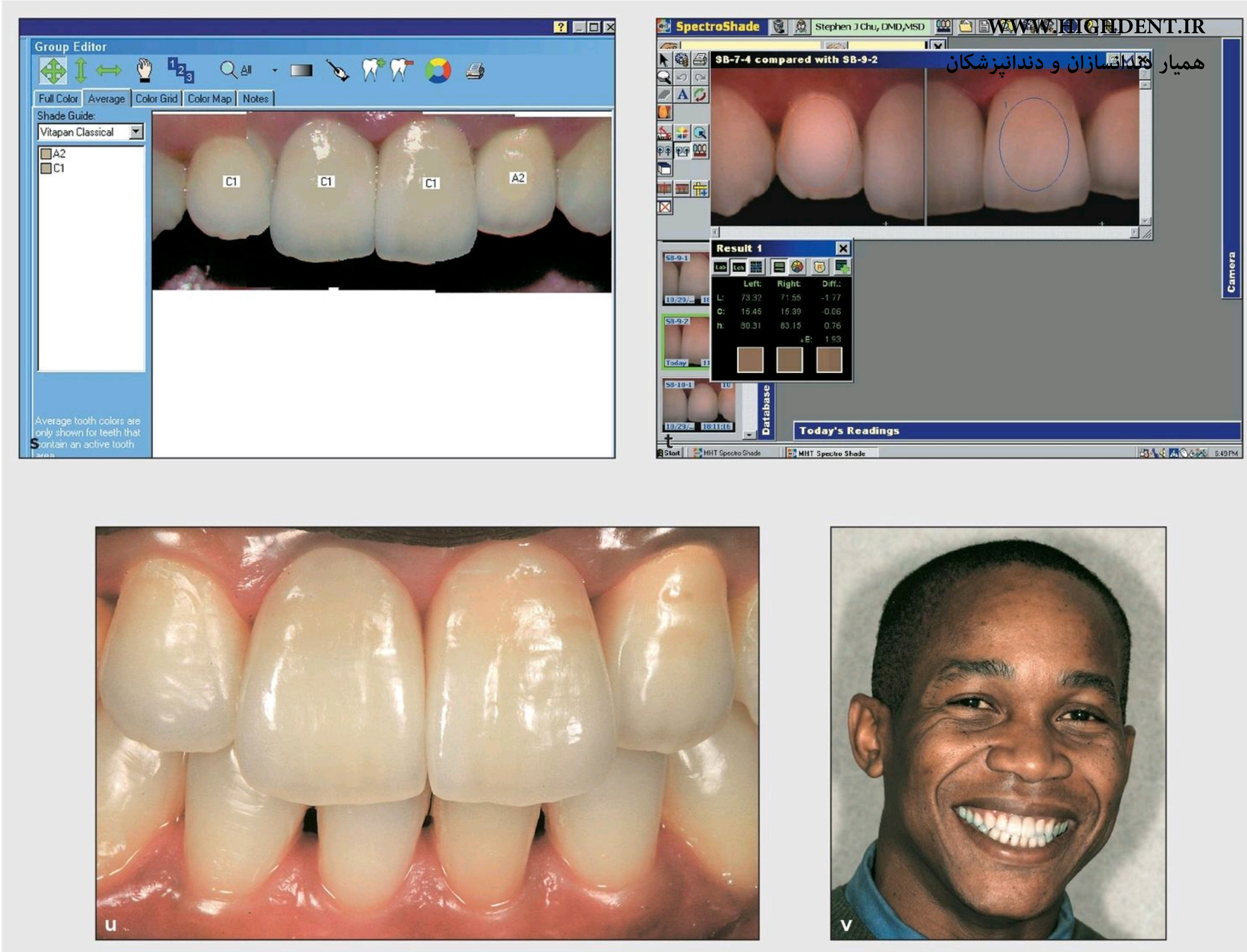


Figs 9-8c to 9-8i



Figs 9-8j to 9-8r

***Figs 9-8s** to 9-8v*

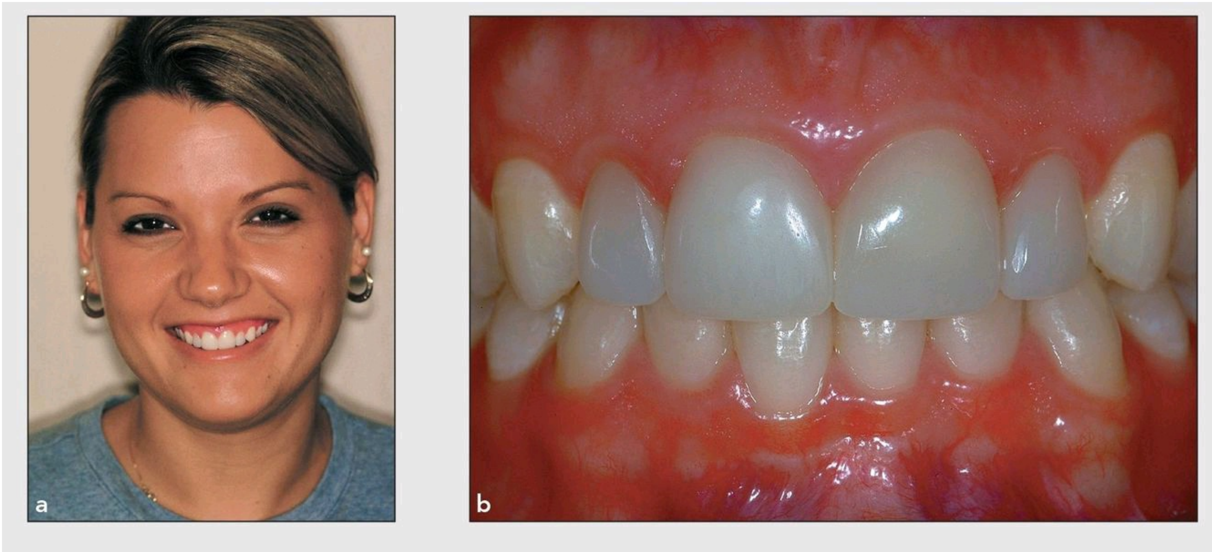


Case 9: Four Anterior Ceramic Laminate Veneers

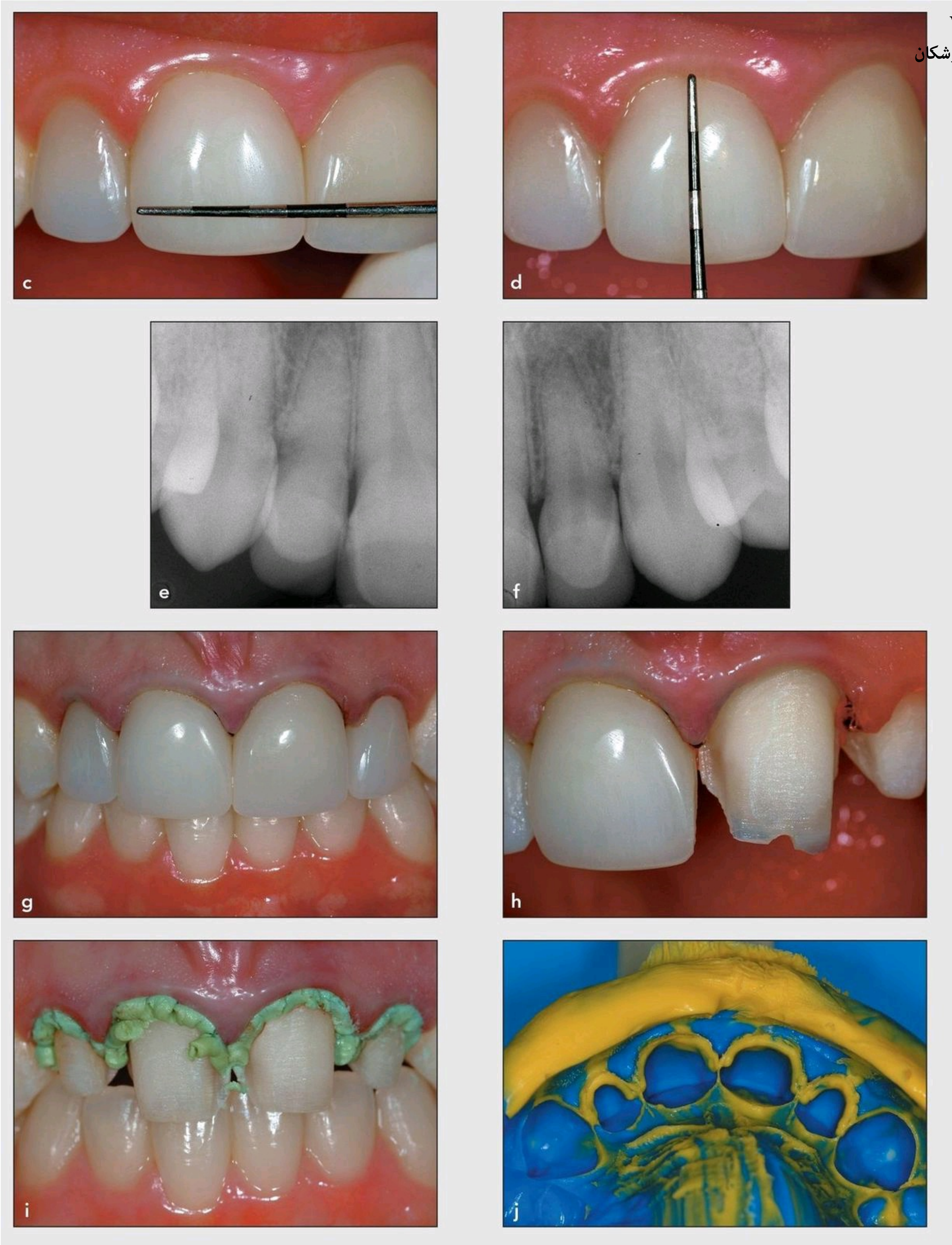
A 25-year-old woman presented with a chief complaint of being dissatisfied with the esthetic appearance of four anterior (pressable leucite-reinforced) ceramic veneers (Empress [Ivoclar-Vivadent]), which had been made for her maxillary lateral and central incisors 2 years prior (Fig 9-9a). Clinical examination revealed discrepancies in the color, value, and proportion of the veneers (Fig 9-9b). Moreover, the teeth had a square shape, as confirmed by measurement with a periodontal probe, which indicated a 100% length-to-width ratio (Figs 9-9c and 9-9d). Radiographic evaluation revealed peg-shaped lateral incisors (Figs 9-9e and 9-9f), and it was determined that space could be gained at the expense of the distal aspects of the central incisors, which would decrease their width and create proper proportion for the four incisors.

A composite mock-up was performed (Fig 9-9g) and the teeth prepared to receive new all-ceramic restorations (Fig 9-9h). A paste deflection tissue management system (Fig 9-9i) was used prior to final impression making (Fig 9-9j). The ShadeVision (X-Rite) system was used for shade analysis, and Vitapan shade B1 was reported (Figs 9-9k and 9-9l). A diagnostic wax-up was made to control final tooth contours and dimensions pretreatment (Fig 9-9m) and posttreatment (Fig 9-9n). The ceramic three-quarter laminate veneers were baked on a refractory cast employing the incisal matrix technique (Figs 9-9o and 9-9p). The veneers were then fitted to the solid cast to define contact areas, gingival embrasures, and emergence profiles (Fig 9-9q). A virtual try-in was performed, and shade was visually assessed and approved prior to adhesive cementation (Fig 9-9r). The final ShadeVision report confirmed that the Vitapan B1 shade was successfully matched (Fig 9-9s), and the clinical presentation confirmed the successful shade match with the surrounding dentition, as well as the improvement in the tooth proportions (Figs 9-9t and 9-9u).

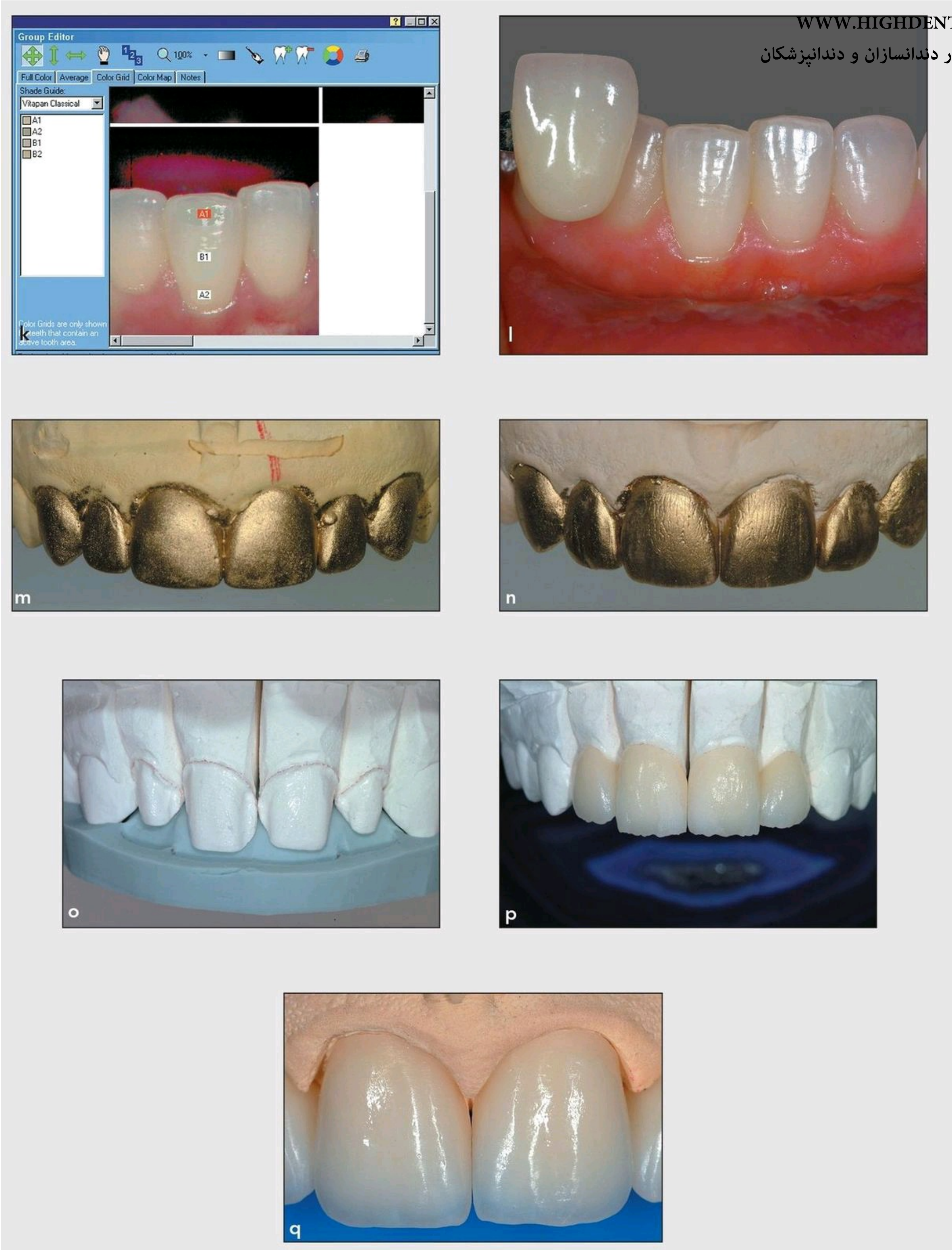
Figs 9-9a and 9-9b



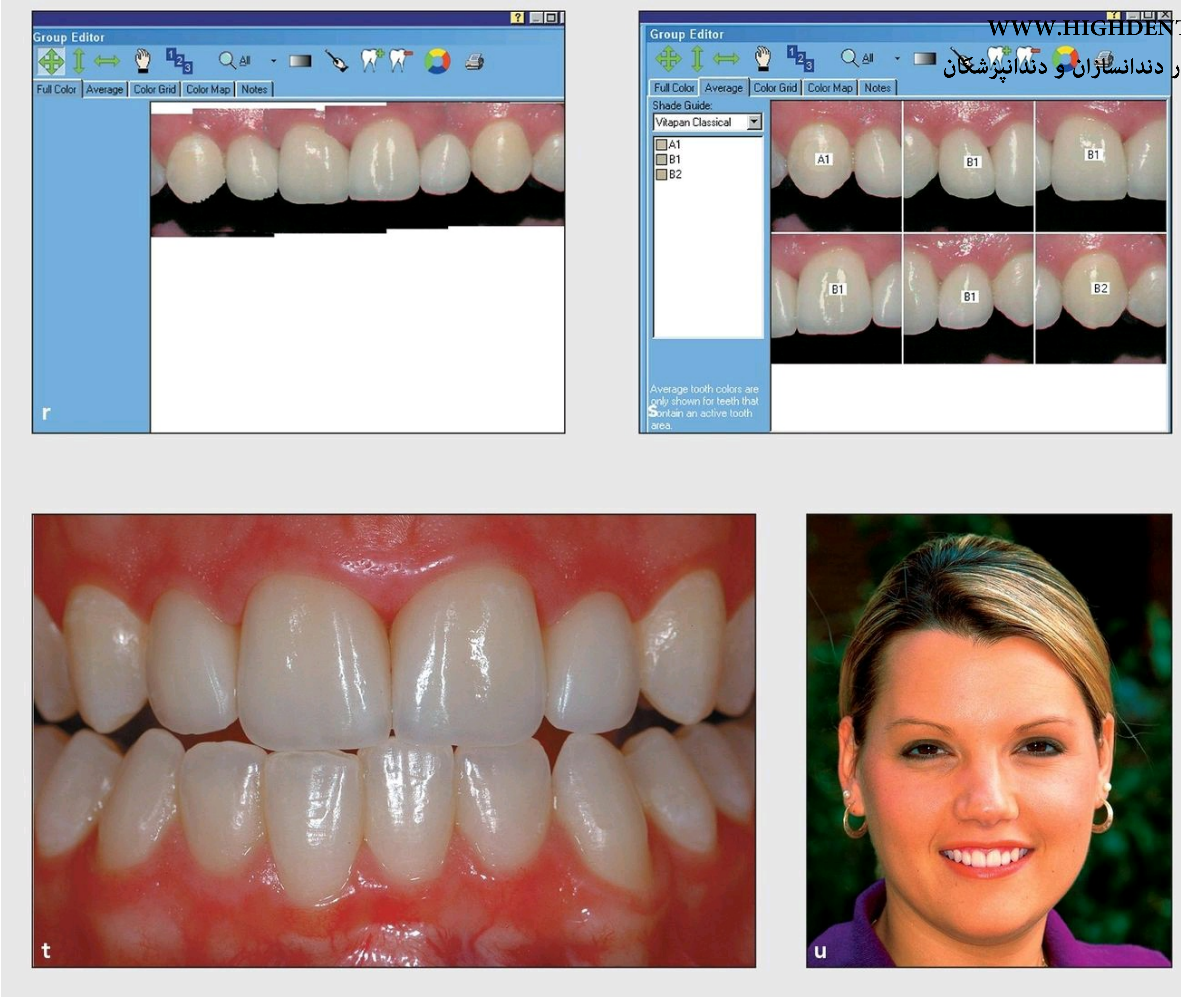
Figs 9-9c to 9-9j



***Figs 9-9k** to 9-9q*



Figs 9-9r to 9-9u

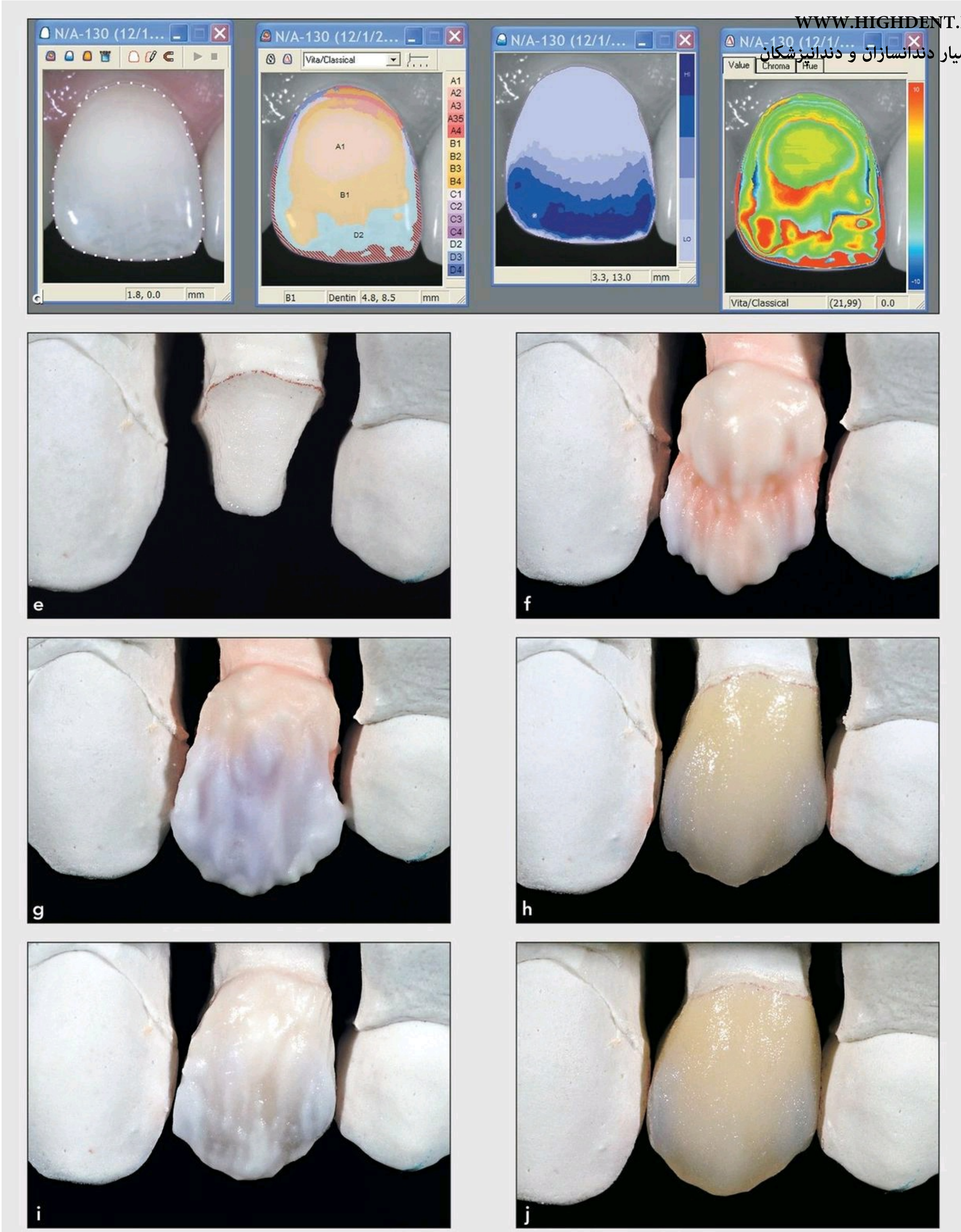


Case 10: Single Posterior All-Ceramic Crown

A maxillary left premolar with an existing large mesio-occlusodistal direct composite restoration was prepared for an all-ceramic full-coverage restoration because of extensive recurrent proximal and cervical caries (Figs 9-10a to 9-10c). Shade analysis was performed using the ShadeScan system, and a Vitapan B1/A1 shade was determined (Fig 9-10d). Technology-based shade matching alone was used in this case, which is often adequate when only the posterior teeth are involved. The ceramic system and the appropriate ceramic powders were selected during shade determination. A refractory cast technique was used to fabricate the crown (Figs 9-10e to 9-10o). The crown was placed using a composite resin cement system (Lute-it [Pentron]), and an esthetic shade match was achieved (Figs 9-10p to 9-10r).

Figs 9-10a to 9-10c

Figs 9-10d to 9-10j



Figs 9-10k to 9-10r

Case 11: Ten Ceramic Laminate Veneers to Match Bleached Teeth

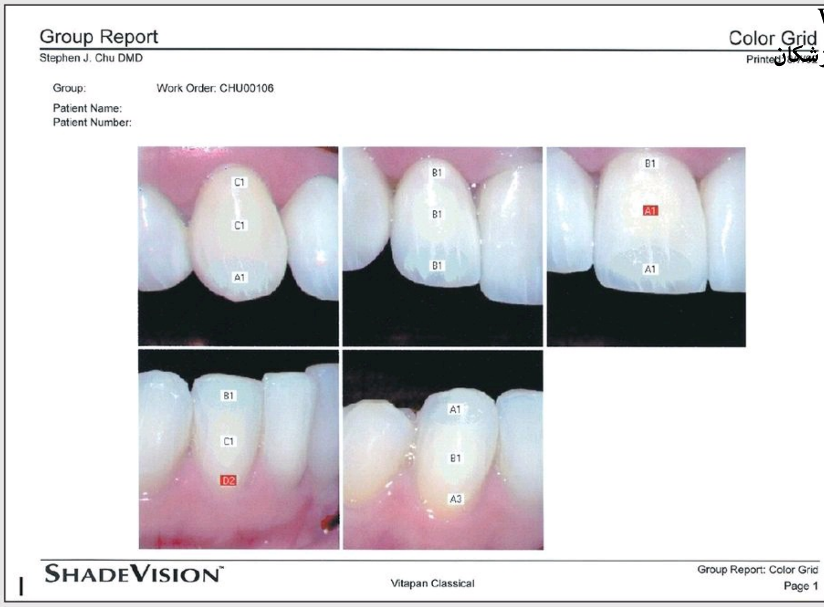
A 50-year-old woman presented with existing composite veneer facings, large interproximal restorations, recurrent caries, and discoloration localized to the maxillary dentition. Dentofacial analysis photographs revealed incorrect tooth proportions and excessive gingival display in the posterior dentition (Figs 9-11a and 9-11b). Prior to esthetic restorative treatment, the mandibular dentition was whitened using a professional take-home vital bleaching system (Colgate Platinum

[Colgate-Palmolive]). A composite mock-up was done to reestablish proper tooth proportions (Fig 9-11c), and controlled-depth tooth reduction was performed (Fig 9-11d). Subsequently, existing interproximal restorations and recurrent decay were removed (Fig 9-11e). The ShadeVision system was used for shade analysis, and a Vitapan D2 gingival shade and a B1 bleached body and incisal shade were selected (Fig 9-11f). These shades were confirmed visually using conventional shade tabs (Figs 9-11g to 9-11i). A refractory cast technique was used to fabricate the ceramic veneer restorations (Fig 9-11j), and many internal cracks and craze lines were layered into the ceramic buildup to match the characterization of the natural dentition (Fig 9-11k). The final ShadeVision report verified a precise clinical and colorimetric shade match to the bleached natural mandibular dentition (Fig 9-11l), which is confirmed by clinical photographs (Figs 9-11m and 9-11n).

Figs 9-11a to 9-11d

Figs 9-11e to 9-11k

Figs 9-11l to 9-11n

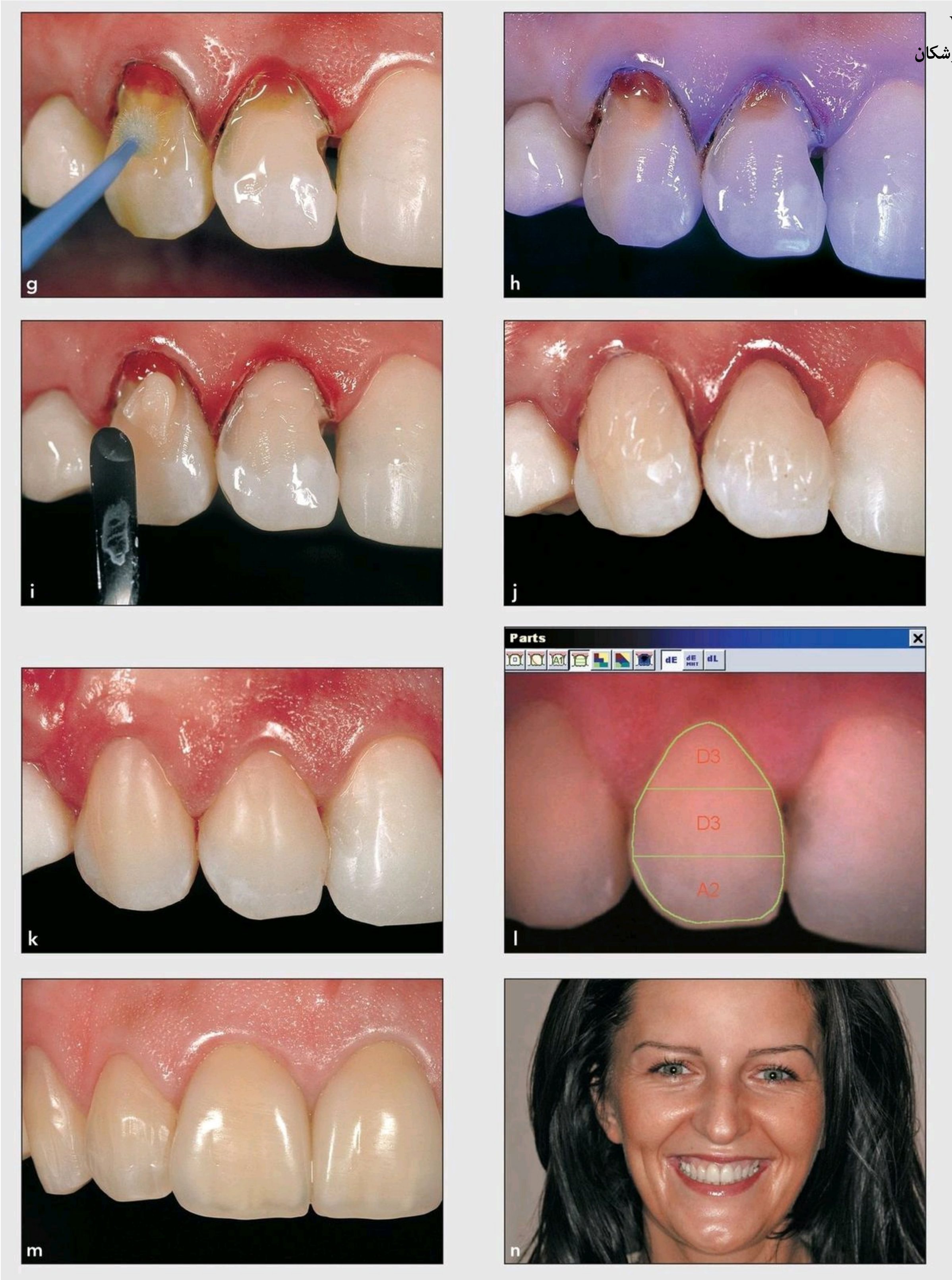


Case 12: Two Anterior Direct Composite Restorations

A 30-year-old woman presented with generalized cervical caries as a consequence of poor diet and nonfluo-ridation of the drinking water system during growth and development (Figs 9-12a to 9-12c). The SpectroShade system was used for shade analysis (Fig 9-12d), and a Vitapan D3 shade was selected. Conventional shade tabs were used to confirm the shade (Fig 9-12e). A direct composite adhesive system (Gradia [GC America]) was used to restore the cervical lesions following caries removal (Figs 9-12f to 9-12k). The shade was verified using the SpectroShade device after finishing (Fig 9-12l). Technology-based shade analysis facilitated the esthetic outcome and clinical success of these direct composite restorations (Figs 9-12m and 9-12n).

Figs 9-12a to 9-12f

Figs 9-12g to 9-12n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dL
D3
D3
A2
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m
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APPENDIX

TABLE A-1 Conversion of Vita Linearguide (Toothguide) 3D-Master tabs to Vita Classical tabs

Vita Linearguide 3D-Master	**VitaClassical**	
	First best match (ΔE*)	**Second best match (ΔE*)**
0M1	B1 (11.0)	A1 (11.7)
0M2	B1 (8.5)	A1 (9.3)
0M3	B1 (5.1)	A1 (5.7)
1M1	B1 (2.9)	A1 (3.4)
1M2	A1 (4.)	B2 (4.3)
2L1.5	B2 (0.8)	A2 (1.5)
2L2.5	A2 (3.8)	A3 (4.2)
2M1	A1 (2.2)	B1 (2.7)
2M2	A2 (0.6)	B2 (1.9)
2M3	A3 (4.5)	B3 (4.9)
2R1.5	A2 (2.7)	B2 (2.9)
2R2.5	A2 (2.3)	A3 (3.3)
3L1.5	C2 (0.9)	D3 (1.4)
3L2.5	B4 (0.9)	B3 (1.3)
3M1	D2 (1.3)	C1 (1.5)
3M2	A3 (1.4)	C2 (2.4)

3M3	B4 (1.4)	B3 (2.3)
3R1.5	D3 (1.6)	C2 (2.8)
3R2.5	A3.5 (1.2)	B3 (2.0)
4L1.5	C3 (1.4)	A3.5 (3.5)
4L2.5	A4 (2.6)	A3.5 (3.6)
4M1	D3 (3.9)	C3 (4.3)
4M2	A4 (1.6)	C3 (3.0)
4M3	A3.5 (4.4)	B4 (4.5)
4R1.5	C3 (3.2)	D3 (4.2)
4R2.5	A4 (2.1)	A3.5 (2.8)
5M1	C4 (3.0)	C3 (6.1)
5M2	A4 (3.6)	C4 (5.2)
5M3	A4 (8.6)	A3.5 (9.6)
Mean color difference*	**3.2 ± 2.5**	**4.0 ± 2.5**

*See Table A-2

TABLE A-2 Conversion of Vita Classical tabs to Vita Linearguide (Toothguide) 3D-Master tabs

Vita Classical	**Vita Linearguide 3D-Master**	
	First best match (ΔE*)	**Second best match (ΔE*)**
A1	2M1 (2.2)	2R1.5 (3.0)
A2	2M2 (0.6)	2L1.5 (1.5)
A3	3M2 (1.4)	3L1.5 (2.8)
A3.5	3R2.5 (1.2)	3L2.5 (2.2)

A4	4M2 (1.6)	4R2.5 (2.1)
B1	2M1 (2.7)	1M1 (2.9)
B2	2L1.5 (0.8)	2M2 (1.9)
B3	3L2.5 (1.3)	3R2.5 (2.0)
B4	3L2.5 (0.9)	3M3 (1.4)
C1	3M1 (1.5)	2M1 (3.9)
C2	3L1.5 (0.9)	3M2 (2.4)
C3	4L1.5 (1.4)	4M2 (3.0)
C4	5M1 (3.0)	4L1.5 (4.3)
D2	3M1 (1.3)	3R1.5 (4.2)
D3	3L1.5 (1.4)	3R1.5 (1.6)
D4	3L1.5 (2.5)	3M2 (2.8)
Mean color difference*	**1.5 ± 0.7**	**2.6 ± 0.9**

The mean color differences show that the Linearguide 3D-Master tabs can be used to mimick Vita classical shades more successfully than vice versa. The mean ΔE of even the second best Linearguide match is lower (ie, more accurate) than Vita Classical's first best match. Note that instrumental findings do not always match visual findings, especially in very small color differences. For example, the second best ΔE* may be 2.5 and the third best ΔE* may be 2.7, but the latter could still be a better visual match.

TABLE A-3 Conversion of Vita Linearguide (Toothguide) 3D-Master tabs to Shofu Vintage Al and ZR veneering porcelain*

Vita Linearguide 3D-Master shade tabs	**Shofu Vintage AL and ZR veneering porcelain shades**
1M1	A1
1M2	B2

2L1.5	B2 + 1/4 B3
2L2.5	B3 + 1/3 B2
2M1	B1 + 1/2 OA-Y[†]
2M2	A2
2M3	B3 + 1/4 B2
2R1.5	A1 + 1/3 OA-Y
2R2.5	A3
3L1.5	D3
3L2.5	B3
3M1	C1
3M2	B3 + A2
3M3	B4
3R1.5	B2 + 1/3 OA-Y
3R2.5	A3 + 1/4 A3.5
4L1.5	C3
4L2.5	A4
4M1	D3 + 1/3 OA-R[º]
4M2	D3 + 1/3 A3.5
4M3	A4 + 1/3 OA-R
4R1.5	C2 + OA-Y
4R2.5	A3.5 + 1/3 OA-V[§]
5M1	1/4 A3 + 3/4 C4 + 1/3 OA-V
5M2	A4 + OA-V
5M3	3/4 A4 + 14 B4 + OA-V + OA-R

* Table reproduced from Shofu Dental Corporation (Shofu.com)

† Opal Amber Yellow

º Opal Amber Red

§ Opal Amber Violet

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