ANATOMICAL FORM DEFINES COLOR: FUNCTION, FORM, AND AESTHETICS

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Contemporary composite materials enable the reproduction of polychromatic effects within a tooth. A broader definition of color that incorporates the anatomy and optical properties of a tooth must be developed so the dental professional can better understand the infinite possibilities of color that exist within the tooth and restoration. This article describes a direct protocol for the development of natural restorations in the posterior dentition through the integration of function, form, and color.

Key Words: color, opalescence, iridescence, aesthetics, hue, value, chroma

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The advent of aesthetic restorative materials requires the clinician to include color in the traditional restorative equation. Due to advances in material science and adhesive technology, the restorative concept has evolved to posit that form follows function,[1,2] and anatomical form defines color. While form has been described in the three dimensions (ie, height, length, and width),[3,4] color provides a more complex description of the optical properties of both the tooth and restorative material (Figure 1). The successful determination and transfer of color to an aesthetic reproduction of the natural dentition depends on the clinician's understanding of the interrelation of these optical properties to the anatomical morphology of the tooth.

Restorative clinicians can now integrate traditional concepts of function and form with knowledge of color and anatomy to create aesthetic restorations. This process requires the clinician to anticipate the definitive function, form, and color in order to achieve an optimal result. This article describes the adhesive technique and protocol for the development of tooth-colored composite restorations in the posterior dentition by integrating the concepts of function, form, and color.

Conventional Definition of Color

Most methods of describing color use a three-dimensional coordinate system that includes hue, chroma, and value.[5] These coordinates define how materials modify light by absorption, reflection, refraction, transmission, dispersion, diffraction, and interference.[6,7] In teeth, hue corresponds to the wavelength of reflected light.[8] As light passes through the natural tooth, it is reflected, refracted, absorbed, or transmitted by a multilayered complex tooth structure that varies according to the optical densities of its hydroxyapatite crystals, enamel rods, and dentinal tubules.[9] Visual stimuli are determined by these reflected or refracted wavelengths, which are transformed in the viewer's cerebral cortex into perceptions of color.[10]

Chroma can be defined as the intensity of a color or the degree of hue saturation (Figure 2). The chromatic component only compares colors of equal hue,[11] and while the same hues are frequently found in the middle and cervical thirds, distinct hues can be identified at the incisal third due to the way light is refracted, reflected, absorbed, and transmitted. Chroma can be varied in the utilization of tints and modifiers to create internal characterization. Value can be defined as the "brightness" of color (in the Vita "R" scale, from the greater to lower value, as with B1, A1, B2, D1, A2, through C4).[11] Value is the most easily discernable of the three primary optical characteristics, and this aspect distinguishes light from dark colors (Figures 3 and 4).[11,12]

Figure 1. The metallic restorative materials of the past such as these gold three-quarter crowns required the restorative dentist to be concerned solely with function and form.

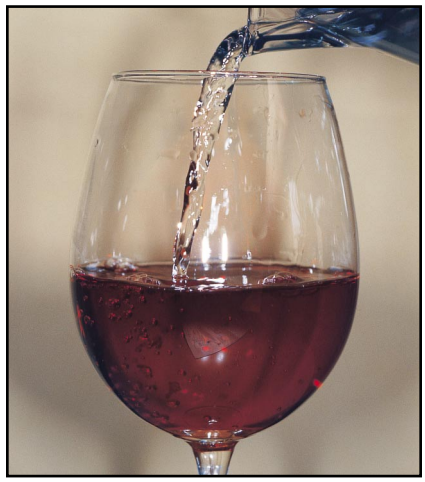


Figure 2. Although the chromatic component of the wine in this glass (Gigondas, 1997) decreases in intensity as water is added, the hue remains the same.

Figure 3. Hue and chroma can be determined by color photographic comparisons.

Figure 4. Value can be determined by black-and-white photographic comparisons of shade tabs.

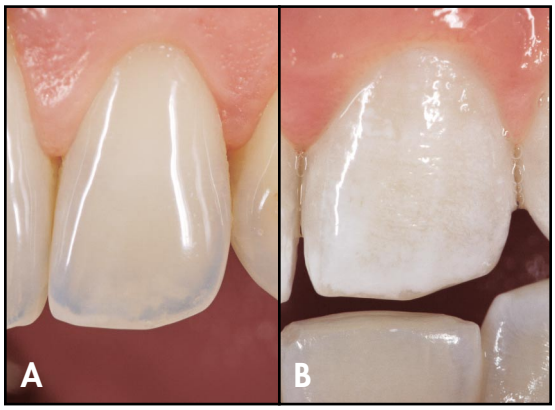


Figure 5A. Aesthetic translucency is evident at the incisal edge and at the mesial and distal incisal angles of the maxillary left lateral. 5B. Observe the opacity in similar regions on another maxillary left lateral incisor.

Figure 6. The opalescent characteristics of the tooth impart a yellow/orange appearance under transmitted light and a bluish appearance under reflected light.

Morphology and Color

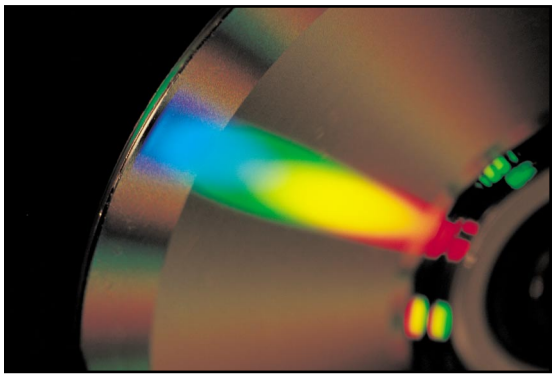
In natural, polychromatic teeth, differing colors are distributed, and various optical characteristics are observed through the enamel and dentin.[10] This polychromatic effect is manifest in different optical characteristics, and the relationships between these characteristics and their role in the natural dentition must be properly interpreted so the clinician can fabricate aesthetic restorations.[13] A broader definition of color is, therefore, necessary based upon anatomy, optical properties, and polychromaticity to appropriately describe tooth color and aesthetics. This definition is based upon the natural dentition and the relative contribution of dentin and enamel to color. Dentin and enamel have drastically different optical properties, and the relative contribution of each should be considered separately during shade determination.

In addition to hue, chroma, and value, more subtle optical properties are also included in the authors' definition of color. These properties include translucency, opacity, opalescence, iridescence, surface gloss, and fluorescence. These secondary optical properties contribute significantly to the total aesthetics of the tooth and may be better explained in terms of tooth anatomy.

Translucency and opacity have been viewed as the most important of these secondary properties, since they are an indication of the quality and quantity of light reflection.[9] The degree of translucency or opacity is determined by the structure and the thickness of enamel and dentin as well as the amount of light that penetrates the tooth or the restoration. Although both dentin and enamel are translucent in natural dentition, the enamel layer is virtually transparent and colorless (Figure 5).[14]

Opalescence can be defined as the milky, iridescent appearance of a dense, transparent medium or colloidal system when illuminated by visible light. Opalescence in the tooth occurs when visible light is scattered and causes a reflection of the shorter wavelengths of light (bluish tones), transmission of longer wavelengths, (yellow-orange), and absorption of medium wavelengths (greenish tones) (Figure 6). This feature is primarily observed in enamel and in teeth it appears as a light-scattering effect that is associated with the diameter of enamel rods. In posterior teeth, these characteristics are exemplified on cusp tips and marginal ridges. In anterior teeth, this effect is observed in the incisal edges and proximal incisal surfaces. Since the color of dentin is dominated by light absorption and reflection that creates a yellow/orange appearance and masks opalescent effects, opalescence is not readily discernible in these structures.

Iridescence produces a rainbow effect within the object being viewed (Figure 7). While colors change



Figur 7. Varying degrees of iridescence can be observed base on the direction, location, and illumination of an object.

Figure 8. Surface morphology of natural teeth influences the surface gloss and color perception. Note the diffuse reflection produced by the macromorphologically roughened or coarse surface.

upon alterations to viewing direction, location, and illumination of an object, the manner in which these parameters change is dependent upon the wavelengths of dispersion, interference, and diffraction of light.

Surface gloss affects the appearance and vitality of teeth and aesthetic dental materials. On the labial surface of anterior teeth, light reflected from tertiary anatomy adds to vitality, whereas less vitality is evident when this anatomy is worn with age. Surface gloss (eg, specular gloss, sheen, luster, distinctness of image gloss) has been described as the optical property that produces a lustrous appearance.[15] Luster is the ratio of light reflected specularly at a material surface to the light diffusely reflected to the surface, and it can be related to any optical scattering that occurs at the surface or within the body of a restorative material.[16] The surface morphology of natural teeth influences the surface gloss. While macro- or micromorphologically roughened or coarse surfaces allow diffuse reflection, flat or smooth surfaces allow specular reflection (Figures 8 and 9).[17] This optical scattering has an effect on the color perception and translucency of the tooth or restorative material, and it should be considered during shade matching between a restorative material and natural tooth structure.[15,18]

Fluorescence occurs when ultraviolet (UV) light rays are absorbed and blue or white visible light is emitted (Figure 10).[17,19] Due to the organic composition of dentin, UV light rays penetrate the enamel and excite the dentin photosensitivity. The emitted light enhances the brilliance and vitality of teeth. Both dentin and enamel fluoresce, and the combination of these structures enhances the whiteness or value of teeth.

Restorative Material Selection

Since composite does not have hydroxyapatite crystals, enamel rods, or dentinal tubules, an illusion of the way light is reflected, refracted, transmitted, and absorbed by these microstructures must be created during the restoration of the occlusal surface.[9] A similar orientation of enamel and dentin is, therefore, required. Contemporary composite resins possess many optical properties that render a polychromatic result, and a variety of hues, translucencies, fluorescencies, and opalescents are available. Color modifiers and opaquing resins can also be layered to enable an infinite number of color combinations.[20] The successful determination and transfer of color to an aesthetic restoration, however, depends on the clinician's understanding and interpretation of color and its relationship to the anatomy of the tooth. The limitations of current composite restorative materials must also be understood.

Dentin Layer

The dentin layer contains varying distributions of yellow, orange, and red color, and it remains thickest at the gingival and central thirds of anterior teeth. While previous generations of composite systems were designed to produce tooth color and translucency with a single filling material, the entire restoration had to be filled with one shade, and multiple shades or modifiers were then incorporated to provide color adjustments. To compensate for this limitation, dentin shades can be placed in the upper two thirds of the tooth, and enamel shades can be placed in the incisal third. When selecting dentin shades, it is important to also consider opacious shades that provide strength and sufficient chroma. It is often

Figure 9. A flat or smooth surface allows specular reflection.

necessary to extend this layer to the dentinoenamel junction (DEJ) in order to maintain the shade and prevent the transmission of a darker, low-value appearance.

Enamel Layer

Although tooth enamel is virtually colorless, these structures possess many of the optical properties (ie, translucency, fluorescence, opalescence, and gloss) that contribute to the vitality of the tooth enamel. These characteristics are exemplified on the cuspal tips and marginal ridges of posterior teeth, as well as the incisal edges and proximal incisal surfaces of anterior teeth. The enamel layer has a white or gray appearance, and remains thickest at the incisal edge of the anterior teeth and thinnest at the cervical aspect. Contemporary enamel shades have high translucency, are fluorescent and opalescent, and maintain a high clinical gloss. Enamel shades tend to reduce the value of a restoration and cannot be used to anatomically replace human enamel. Although enamel shades can be used on incisal edges and cuspal surface, the shade of the restoration is ultimately provided by the dentin shades. If enamel shades are used to cover the entire labial surface, the materials must be layered and used sparingly at the cervical third.

Shade

Due to the variety of colors and their orientation within natural teeth, appropriate shade selection remains challenging for composite restorations. Since composite materials are monochromatic and cannot duplicate the complex orientation of the colors seen in the natural dentition, a variety of resin shades must be selected to provide natural aesthetics.[21] Arbitrary and subjective shade designations (eg, universal, yellow, light) further complicate precise shade selection. Since the standard shade guides for composite resins are manufactured with unfilled methacrylates, they do not accurately represent the true shade, translucency, or opacity of the final polymerized restorative material.[11] In addition, many of the composite systems are synchronized to a shade guide (ie, Vita Lumin, Vident, Brea, CA), that was designed for porcelain, not resins. Since many shade tabs are fabricated using this basis, custom shade tabs may be beneficial for a variety of direct applications.

Tints

Tints can be applied during the stratification process to adjust the hue and chroma of the restoration, lower its value, and establish natural characteristics for a specific area of the tooth. Tints can also be placed over the dentin-colored composite and beneath the artificial enamel to enhance the realistic distribution of color throughout the restoration. Contemporary resins are generally translucent and colored with pigments or dyes to achieve the desired optical effect. Opaquers can be used to conceal light or dark underlying structures, and they can be applied to duplicate difficult-to-match areas (eg, hypocalcification).

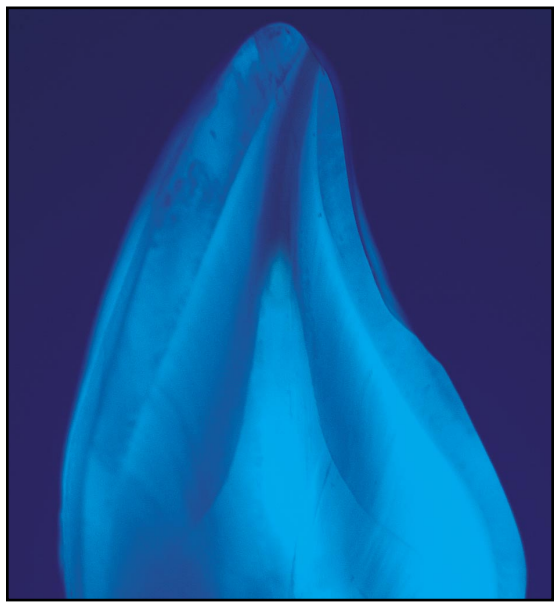


Figure 10. Natural teeth exposed to ultraviolet (UV) light rays possess fluorescence with an emission spectrum that varies from intense white to light blue.

Figure 11. Preoperative occlusal view of a defective amalgam restoration.

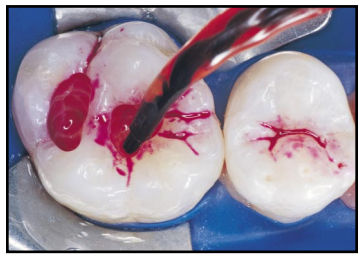


Figure 12. A caries-disclosing solution was applied to facilitate detection and identification of the irreversibly infected carious tissue.

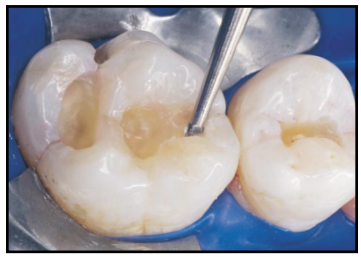


Figure 13. The carious tooth structure was removed as indicated by the reapplication of caries-detecting dye.

Figure 14. Occlusal view of the completed preparation.

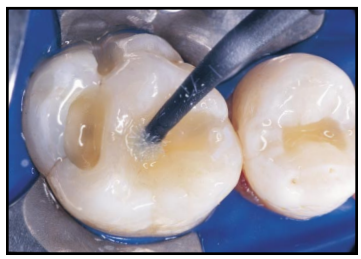


Figure 15. An A3 shaded flowable composite was injected as the syringe tip was slowly removed and uniformly distributed.

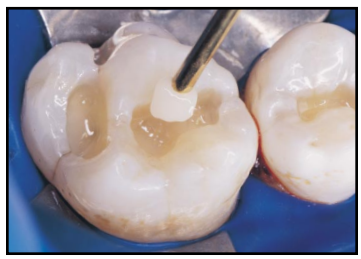


Figure 16. An A3 shaded opacious hybrid composite was applied in increments using a lateral condensation technique.

Operative Procedure

Prior to initiating the restorative procedure, an occlusal analysis of tooth morphology is performed, and a shade map is created to communicate existing dentin and enamel intercolor contrasts, translucency patterns, crazing, hypocalcification spots, incisal and gingival blending, and/or occlusal stain patterns. The preoperative shade and orientation of composite resins, tints, and modifiers is also recorded. Shade selection should be accomplished prior to rubber dam placement to prevent improper color matching as a result of dehydration and elevated values (Figure 11).[22] Preoperative occlusal stops and excursive guiding planes can be recorded with articulation paper and transferred to an occlusal diagram, recorded using a digital camera, or reviewed on a stone model. This registration may facilitate the placement of centric stops beyond or within the confines of the restoration, determination of proper restorative material thickness, and minimize finishing procedures.[23]

Restorative Stage

Once anesthesia is administered, the treatment site is isolated with a rubber dam to achieve adequate field control and protect against contamination. Upon removal of any existing restorations, a caries-disclosing solution (eg, Seek, Ultradent Products, South Jordan, UT) can be applied to the internal surfaces of the preparation, occlusal fissures, and grooves to facilitate carious tissue detection and removal (Figures 12 and 13).[24] Any carious dentin can then be removed using slow- and high-speed carbide burs and spoon excavators (Figure 14). The occlusal outline should include carious enamel, provide access to the carious dentin, remove any residual amalgam staining on the molar, and provide access for the application of restorative materials. Healthy tooth structure should only be removed when the occlusal outline requires extension beyond or within the previously indicated functional stops. Preparations can then be completed with a finishing diamond, cleaned with a 2% chlorhexidine solution, (eg, Consepsis, Ultradent Products, South Jordan, UT), rinsed, and lightly air dried.

Adhesive Protocol

The "total-etch" technique can be used to minimize potential microleakage and enhance bond strength.[25-27] The prepared tooth surfaces should be etched for 15 seconds with

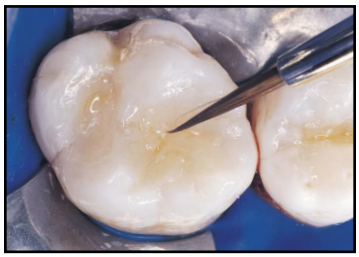


Figure 17. An ochre-tinted resin was applied in the previously formed invagination and polymerized for 10 seconds.

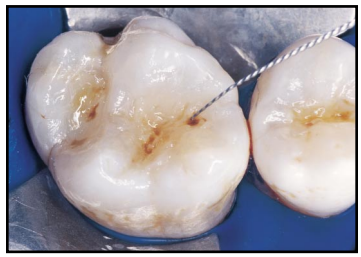


Figure 18. A brown tint was used to create the illusion of occlusal fissure staining.

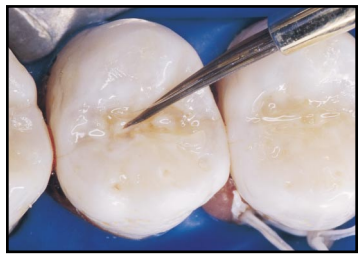


Figure 19. A diluted whitewash was applied to create the milky white stains indicated during the preoperative shade-mapping procedure.

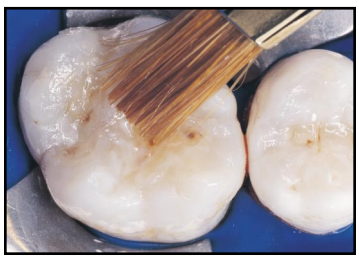


Figure 20. A clear, translucent hybrid composite was sculpted with a curved metal instrument and smoothed with a sable brush.

Figure 21. The occlusal anatomy was refined using #12 and #30 fluted, egg-shaped finishing burs.

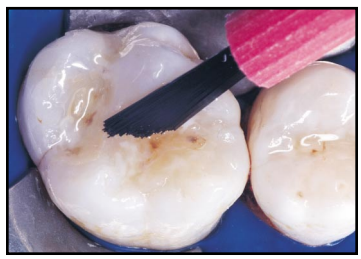


Figure 22. The margins were etched with a 37.5% phosphoric acid and a composite surface sealant was applied and cured to seal any cracks or microscopic porosities.

37.5% phosphoric acid, rinsed for 5 seconds, and gently air-dried for 5 seconds. A light-cured adhesive (eg, Optibond Solo Plus, Kerr/Sybron, Orange, CA) can then be applied with a disposable applicator for 20 seconds using a continuous motion and reapplied every 5 seconds. Any excess material can be removed with the applicator, and the agent should be light cured in "boost" mode for 10 seconds. Although a small amount of excess adhesive can be applied over the margins to improve sealing, this excess should be removed during finishing procedures.

While pulp tissues have demonstrated the inherent ability to repair, heal, and to form reparative mineralized bridges under several restorative materials,[28] recent studies reveal that the failure of composite restorations may be related to adequate sealing and adaptation of the tooth/restorative interface.[28] Bacterial infiltration and microleakage have been attributed to pulpal inflammation and necrosis of exposed vital dentin, regardless of the restorative material selected.[28] The use of nonadhesive restorative materials (eg, calcium hydroxide), however, may generate a gap at this interface and result in bacterial colonization.[28,29] The hybridization of the exposed dentin with an adhesive system effectively protects this pulp-dentin interface, provides resistance to microleakage, and allows retention of the restoration, regardless of the depth of the preparation.[28,30]

Internal Adaptation

The use of a flowable composite resin allows the adhesive system to develop an intimate contact with the dentin bonding agent and enhanced internal adaptation.[29] An A3 shaded flowable composite (eg, Revolution, Kerr/Sybron, Orange, CA) can be injected as the syringe tip is slowly removed and uniformly distributed with a composite applicator (Figure 15). This technique reduces the possibility of entrapping bubbles and ensures optimal adaptation of the resin material to the adhesive interface. A small increment (1 mm to 2 mm in thickness) can then be applied to the pulpal floor of a Class I cavity preparation. Confining the curing thickness to 2 mm or less of composite will result in reduced shrinkage and stresses, and it improves marginal adaptation.[31]

The "Artificial Dentin" Layer

The preparation should be incrementally filled with an A3 shaded hybrid composite (eg, Point 4, Kerr/Sybron,

Orange, CA) based on the shade selected during the preoperative mapping procedure (Figure 16). An opacious dentin replacement with an increased color saturation should be used for enhanced light reflection. Each increment should be gently condensed to ensure complete adaptation to the underlying resin and tooth structure. A composite hybrid with a low volumetric polymerization shrinkage can also be used to reduce the possibility of cuspal flexure. The hybrid can also be diagonally layered in 1-mm to 2-mm increments to further reduce potential failure. Feathering the material up the cavity wall according to the anatomical contours will minimize shrinkage and reduce intercuspal stress. Each increment should be light cured for approximately 10 seconds using the boost mode (Optilux 501, Sybron/Kerr, Orange, CA), and the composite resin should be methodically condensed and shaped to correspond to cusp development and dentin replacement.

Once the dentin layer is developed, an invagination is made with an interproximal instrument (eg, IPCL TN, Cosmedent, Chicago, IL) while the material is soft. A thin layer of resin can be applied and cured to create a "light diffusion layer" and provide an illusion of depth for restorations of limited thickness. This translucent layer will cause an internal diffusion of light and control luminosity within the internal aspects of the restoration. Internal characteristics (eg, pits, fissures, grooves) can then be applied, and an ochre-tinted resin can be applied in the predetermined regions; untinted resin can be used to dilute any areas of excess chroma (Figure 17). These tints should be polymerized prior to the placement of additional stratification materials to stabilize the characterization and prevent mixing of colors (Figure 18). A smooth, natural transition can be obtained between the occlusal planes and higher-valued tooth structures using diluted whitewashed shades, and any necessary staining can be developed at this time (Figure 19). This color variation allows the development of a three-dimensional appearance within the restoration.

The "Artificial Enamel" Layer

In order to allow space for the proper enamel thickness and position, the definitive aesthetic result should be visualized during the development of the artificial dentin and internal characterization stages. A clear, translucent-shaded (T-1) hybrid composite (eg, Point 4, Kerr/Sybron, Orange, CA) should be sculpted with a curved metal instrument and smoothed with a sable brush to reproduce form in addition to the optical effects of enamel (Figure 20). This procedure will provide aesthetic translucency and allow development of functional and anatomical occlusal morphology.

Figure 23. The final polish was performed with rubber points (FlexiPoints, Cosmedent, Chicago, IL) and polishing cups (Enhances Polishing Cups, Dentsply/Caulk, Milford, DE).

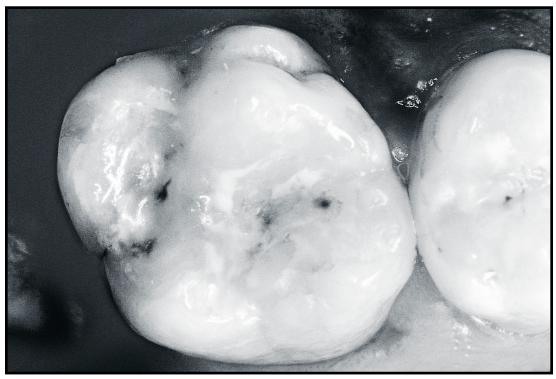


Figure 24. Black-and-white photography was used to verify the definitive value and light reflectance.

Figure 25. Postoperative occlusal view of the definitive restorations reflects the harmonious integration of color with anatomical form and function.

Finishing and Polishing

Occlusal refinement can be achieved with fluted, egg-shaped finishing burs, and the lingual surfaces should be finished using needle-shaped burs (Figure 21). Once the initial finishing procedures are complete, the margins and surface defects can be sealed. All accessible margins can be etched using a 37.5% phosphoric acid semi-gel, rinsed, and dried. A thin layer of composite surface sealant (OptiGuard, Kerr/Sybron, Orange, CA) should then be applied to all margins with a brush and cured to seal any cracks or microscopic porosities that may have formed during the finishing procedures (Figure 22). Rubber points (FlexiPoints, Cosmedent, Chicago, IL), polishing cups (Enhance Polishing Cups, Dentsply/Caulk, Milford, DE), and regular and extrafine composite resin polishing paste (Prisma-Gloss/Prisma-Gloss Extra Fine, Dentsply/Caulk, Milford, DE) should then be incorporated for the final polishing procedures (Figure 23). Occlusal contacts and centric, protrusive, and lateral excursions should be evaluated following rubber dam removal. Any necessary equilibration can be accomplished with #12 and #30 egg-shaped finishing burs, and the final polish should be repeated. Interproximal contacts should be evaluated using unwaxed floss to ensure the absence of sealant in the contact zone, and the margins should be inspected (Figures 24 and 25).

Conclusion

Form and function are interdependent aspects of the restorative formula. The restorative clinician can now integrate traditional restorative concepts of function and form with an understanding of color and anatomical morphology for the development of aesthetic restorations. A precise protocol is required for the incremental application of composite resins, tints, and modifiers to enable the creation of natural-looking restorations. While this article primarily focuses on the parameters of color and aesthetics within directly fabricated restorations, Part II of this discussion will address this critical aspect within laboratory-fabricated restorations. Regardless of the type of restoration selected, the definitive aesthetic result will be based on the professional's ability to create a "form that follows function," and imagination and artistry to ensure that the anatomical form defines color.

Acknowledgment

The authors declare no financial interest in any of the products cited herein.

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Continuing Education (CE) Exercise No. 2

To submit your CE Exercise answers, please use the answer sheet found within the CE Editorial Section of this issue and complete as follows: 1) Identify the article; 2) Place an X in the appropriate box for each question of each exercise; 3) Clip answer sheet from the page and mail it to the CE Department at Montage Media Corporation. For further instructions, please refer to the CE Editorial Section.

The 10 multiple-choice questions for this Continuing Education (CE) exercise are based on the article "Anatomical form defines color: Function, form, and aesthetics," by Douglas A. Terry, DDS, Willi Geller, CDT, Olivier Tric, CDT, Mark J. Anderson, CDT, Monte Tourville, CDT, and Alvin Kobashigawa, BS. This article is on Pages 59-67.

Learning Objectives:

This article presents a modified definition of color and incorporates an analysis of the anatomical morphology and optical properties of a tooth to facilitate a thorough shade determination. Upon reading this article and completing this exercise, the reader should:

- Understand the infinite possibilities of color that exist within the tooth and restoration.
- Be aware of the adhesive protocol for the development aesthetic posterior composite restorations.

1. All of the following three-dimensional properties have been traditionally used to define color EXCEPT:
a. Hue.
b. Value.
c. Chroma.
d. Texture.

2. Once the artificial dentin layer is developed, an invagination is made and a "light diffusion layer" should be placed for all of the following reasons EXCEPT:
a. To provide sufficient opacity to conceal underlying discolored structures.
b. To provide an illusion of depth for restorations of limited thickness.
c. To cause an internal diffusion of light.
d. To control luminosity within the internal aspects of the restoration.

3. The term "hue" corresponds to:
a. The intensity of a color.
b. The wavelength of reflected light.
c. The principle determinant of light from dark colors.
d. The iridescent appearance of a dense medium or colloidal system when illuminated.

4. Opalescence in teeth appears as a light-scattering effect that is associated with the diameter of enamel rods. Where is this occurrence most visible in the natural or restored dentition?
a. On the cusp tips and marginal ridges of posterior teeth.
b. In the incisal edges and proximal incisal surfaces of anterior teeth.
c. Both a and b.
d. Neither a nor b.

5. What effect does iridescence produce on natural and restored dentition?
a. A lustrous appearance is produced.
b. An emission of blue or white visible light.
c. A rainbow effect within the object being viewed.
d. All of the above.

6. The surface morphology of natural teeth influences the surface gloss. While macro- or micromorphologically roughened or coarse surfaces allow diffuse reflection, flat or smooth surfaces allow specular reflection.
a. Both statements are true.
b. Both statements are false.
c. The first statement is true, the second statement is false.
d. The first statement is false, the second statement is true.

7. Why are tints and opaquers applied during the direct stratification process?
a. To adjust the hue and chroma of the restoration.
b. To enhance the realistic distribution of color throughout the restoration.
c. To lower value of the restoration and establish natural characteristics for a specific area of the tooth.
d. All of the above.

8. Which of the following effects result in light alteration for subsequent color variances?
a. Reflection and refraction.
b. Absorption and transmission.
c. Dispersion, diffraction, and interference.
d. All of the above.

9. During preparation for direct posterior restorations, the occlusal outline should:
a. Provide access to the carious dentin.
b. Include and remove carious enamel.
c. Remove any residual amalgam staining and provide proper restorative access.
d. All of the above.

10. How is a 3-dimensional appearance developed within a restoration during the final stratification process?
a. By the application of internal characteristics and aesthetic staining.
b. By the placement of a diluted whitewashed shade between the occlusal planes and higher valued tooth structures.
c. Both a and b.
d. Neither a nor b.