Shade and translucency matching are fundamental aspects in esthetic dentistry. The ultimate goal is to create tooth-like restorations; however, natural teeth also show fluorescence, which must be simulated to achieve ideal esthetic results.

Fluorescence is defined as luminescence that occurs when energy is supplied by electromagnetic radiation, usually via ultraviolet (UV) light. The energy source transfers an electron of an atom from a lower energy state to a higher, “excited” energy state. The electron releases energy in the form of light (luminescence) when it falls back to a lower energy state. Fluorescent substances absorb the UV light and re-emit it almost instantaneously. Since some energy is lost in this process, the emitted light has a longer wavelength than the absorbed radiation, which makes this light visible and causes the material to “glow.”

**FLUORESCENCE OF NATURAL TEETH**

In 1911, Stubel\(^1\) was the first to describe the fluorescence of natural teeth under UV light (\(\lambda_{\text{max}} = 450\) nm).\(^2\) In 1953, Hartles and Leaver\(^3\) further examined the fluorescence of different tooth structures and reported that enamel exhibits “normal” fluorescence with a bluish white appearance, occasionally tinged with yellow. They also confirmed findings by Benedict\(^4\) in 1928 that dentin has much greater fluorescent properties than

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enamel. This greater fluorescence is due to the higher organic content of dentin.\textsuperscript{3,5,6} Color is most intense in the apical regions, particularly in immature teeth with open apices.\textsuperscript{3} Cementum shows similar fluorescence to dentin, but less intense. Carious enamel does not provide fluorescence, and the carious areas appear black.\textsuperscript{7–9} Even the initial whitish patches will lose their fluorescence. Carious dentin also lacks fluorescence and appears black or dark brown under UV light.\textsuperscript{7,8} The fluorescent intensity of dentin increases with age.

Fluorometric investigations revealed that a complex of cross-linked collagen with hydroxyapatite is a possible fluorescing compound within the tooth tissue.\textsuperscript{2,6}

When the organic structure of a tooth is affected by, for example, caries or pulpal necrosis, the tooth loses its vitality under both natural and UV light and appears dark brown. Therefore, less fluorescence correlates with lesser value. This effect, however, can be reversed in natural teeth using internal tooth bleaching (Case 1, Figs 1 to 6).

Due to the differences between sound and carious tooth structures, fluorescence is increasingly used for reliable and noninvasive caries detection.\textsuperscript{9–12} It even serves as a screening method for oral cancer since abnormal oral mucosal lesions appear dark brown or black under UV light.\textsuperscript{13}
FLUORESCENCE OF DENTAL MATERIALS

The goal of esthetic restorative dentistry is to mimic the optical properties of natural teeth. However, the fluorescence of natural teeth is greatly overlooked in restorative dental materials. Fluorescence adds to the vitality of a restoration and minimizes the metamer effect between teeth and restorative materials under various light conditions.

Modern composite resins used for anterior tooth restorations contain fluorescent pigments to simulate the lively expression of natural teeth in all types of light. Many modern composite resins have fluorescence wavelength peaks of 440 to 450 nm, which is comparable to natural dentin. However, there is still a considerable variation in fluorescence between different composite systems and between some composite resins and natural teeth.

Modern veneering porcelains and ceramic coping materials are intended to mimic the optical qualities of natural teeth (Fig 7): translucency, color (hue, chroma, value), fluorescence, and opalescence. These characteristics are not only crucial for the restoration itself, but also to reduce the “shadowing effect” at the restorative-gingival interface and to provide a healthy-looking gingival architecture. In fact, the creation of an inconspicuous dental restoration starts with well-designed prosthetic contours and natural, healthy integration within the surrounding soft tissues. Feldspathic veneering porcelains typically contain particles that provide fluorescence. It is important that all components of a porcelain system, including opaquers, dentin, enamel, stains, and even glazing agents, are fluorescent. However, fluorescence is often not homogenous within the same porcelain system or among different systems. Various techniques and components have been suggested to achieve natural-looking fluorescence.

Proper positioning of varying degrees of fluorescence on the tooth is crucial for natural esthetics. Roots and dentin reveal the strongest fluorescence, while enamel shows the weakest. Figure 8 demonstrates tooth characteristics under various light conditions. Veneering porcelain powders reveal different opacities, translucencies, and fluorescence under transmitted light (Fig 9) and UV light (Fig 10).
Porcelain Laminate Veneers

Case 2 (Figs 11 to 14) depicts porcelain laminate veneers that were placed on two central incisors over 10 years ago, exhibiting a favorable blend with the natural dentition under natural and UV light. In such an ideal situation, the abutment color already provides the total value of the final restoration, and only different chromatic dentin and incisal layers are needed. Differences in opacity and translucency as well as the reduced degree of fluorescence among enamel, dentin, and shoulder porcelain are apparent.

Fig 11 Extraoral view of the central incisors restored with feldspathic porcelain.
Fig 12 Feldspathic porcelain restorations under UV light.
Fig 13 Periapical radiograph.
Fig 14 Ten-year follow-up view.
Case 3 (Figs 15 to 30) demonstrates the use of dental ceramics for full-coverage restorations. Selection of the coping material was the first step because even different metal-oxide ceramics (e.g., alumina and zirconia) provide considerably different optical properties (Figs 21 and 23). Alumina (Procera, Nobel Biocare, Gothenburg, Sweden) was ultimately selected as the coping material due to its favorable esthetic properties. Fluorescence was controlled through liners, shoulder ceramics, and internal stains, which were applied in the gingival area to support light distribution and optimal integration with the highly fluorescent dentin tooth structure (Fig 24). The importance of the shoulder location in the gingival area is obvious under UV light (Fig 25). Light is distributed to the surrounding structures and soft tissues, such as marginal gingiva and papillae. Dentin ceramic masses were applied in different chromas and saturations toward the incisal aspect of the tooth. The incisal third of a natural tooth features the highest degree of translucency. The actual tooth shade

**Full-Coverage Crowns**

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is achieved through the colors at the center of the tooth to simulate the natural core dentin. After a full-contour build up, cutback was performed in an irregular manner to enhance internal effects. Enamel mixtures with bluish opalescent translucent powders were applied to provide a more vivid restoration. Some teeth have distinct mamelons, which are typically located underneath the natural enamel and are more opaque than normal dentin and highly fluorescent. Mamelons should be placed between the enamel and the transparent layers. The final shape is typically completed using a few translucent characteristics or transparent enamel powders to provide the impression of depth. Translucent materials should always receive minimal firing to protect the characteristics of a natural-looking restoration. Surface texture and luster intensity may affect reflective features of the restoration and should ultimately be the responsibility of the clinician.

Fig 22 Intraoperative view of the bleached abutment tooth during crown preparation.

Fig 23 Fluorescence of the bleached abutment tooth under UV light.

Fig 24 Definitive alumina-based crown after cementation.

Fig 25 The crown exhibits the same fluorescence as the neighboring natural teeth under UV light.
Fig 26 Preoperative view of porcelain-fused-to-metal crown.

Fig 27 Preoperative periapical radiograph.

Fig 28 Extraoral view of the alumina crown.

Fig 29 Postoperative periapical radiograph.

Fig 30 Intraoral view of the definitive crown.
**Single-Implant Restorations**

Zirconia has gained tremendous popularity as an implant abutment material in the esthetic zone because it prevents the grayish appearance of the surrounding soft tissues often seen with titanium or other metal-alloy abutments. The availability of colored zirconia abutments in different shades further improves esthetic outcomes over the conventional, white zirconia. In thin soft tissue situations, however, fluorescence may actually play a greater role than color. Fluorescence provides natural illumination and light transmission of the soft tissue at the implant-restorative interface and eliminates the shadowing effect that may appear when tooth-colored abutments are used.

Cases 4 through 6 demonstrate the optical properties, selection, and fabrication of fluorescent zirconia abutments.

Case 4 (Figs 31 to 45), in which the mandibular right central and lateral incisors were replaced with implant-supported single crowns, demonstrates the difficulty of perfectly matching all optical properties of the natural teeth and soft tissues with conventional materials and techniques. The central incisor crown was supported by a titanium abutment, and the lateral incisor crown was supported by a zirconia abutment (Figs 42 and 43). While the definitive crowns blended favorably with the remaining dentition in some light conditions, the use of UV light, transmitted light, and postoperative photographs revealed esthetic deficiencies, espe-

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**CASE 4**

**Fig 31** Smile view after implant-crown restoration of the mandibular right central and lateral incisors.

**Fig 32** Intraoral view of implant-supported crown restorations under natural light.

**Fig 33** Fluorescent properties of the crowns and neighboring natural teeth.

**Fig 34** Black-and-white photograph of the implant-supported crowns.
cially in the surrounding soft tissues (Figs 44 and 45). These deficiencies were due to the abutment materials (titanium) and, even for the zirconia abutment, to the lack of fluorescence at the abutment-restoration interface.

Recently, colorants and fluorescent modifiers have been developed that can be applied to zirconia abutments even after milling and finishing. Figures 39 and 40 show the optical properties of conventional versus colored zirconia abutments under natural and UV light. Fluorescence is achieved by dipping the abutment or framework into a fluorescent coloring liquid before sintering (Colour Liquid Fluoreszenz, Zirkonzahn, Gais, Italy). The abutment is blow dried after the dipping process to remove excess and placed under a drying lamp to prevent damage to the heating elements of the sinter furnace. Sixteen coloring liquids for zirconia (Zirkonzahn) are also infiltrated during the sintering process. Figures 42 and 43 show conventional versus colored zirconia abutments after applying fluorescence under natural and UV light.

The creation of natural esthetics with implant-supported restorations requires highly fluorescent properties at the implant-restorative interface and the gingival third of the restoration (Figs 44 and 45). Fluorescence and color can be added to zirconia to a certain degree. It is still difficult to create a dark shade (eg, C3 or C4) with a high degree of fluorescence since the dark color pigments may overshadow the fluorescent properties. Therefore, strong fluorescence of the implant abutment may actually be more important for overall and especially gingival esthetics than the shade itself.

Fig 35 Intraoral view of the zirconia and titanium abutments.

Fig 36 Periapical radiograph of the definitive implant crowns.

Fig 37 Optical behavior of crowns on a zirconia versus a titanium abutment under transmitted light.

Fig 38 Postoperative intraoral view. Note the unfavorable soft tissue color especially around the titanium abutment, but also around the zirconia abutment.
Fig 39 Conventional zirconia versus colored zirconia abutments under natural light.

Fig 40 Conventional zirconia versus colored zirconia abutments under UV light.

Fig 41 Fluorescence is added by infiltrating the zirconia with fluorescent colorants. The abutment is dipped into the colorant and fully sintered or sintered again.

Fig 42 Zirconia abutments after application of fluorescence (Zr + Fl) under natural light. In addition to fluorescence, shade-modifying colorants were applied (A1, B1, C1, D2).

Fig 43 Zirconia abutments after application of fluorescence (Zr + Fl) and colorants (A1, B1, C1, D2) under UV light. Note the negative effect of coloring pigments on the degree of fluorescence.

Fig 44 Regular zirconia abutment (Zr) versus a natural tooth and fluorescent zirconia abutment (Zr + Fl) under natural light.

Fig 45 Regular zirconia abutment (Zr) versus a natural tooth and fluorescent zirconia abutment (Zr + Fl) under UV light.
In case 5 (Figs 46 to 56) a provisional implant crown was placed at the maxillary left central incisor site to condition the soft tissue morphology after implant placement (Fig 46). The provisional restoration remained in place for 6 weeks until the position of the soft tissue was stabilized. The optical differences between a conventional and a fluorescent zirconia abutment are evident under different light conditions (Figs 47 to 49). Alumina was selected as the coping material for the definitive crown on the zirconia abutment. Figures 50 to 56 show the preoperative and postoperative situation after implant placement and fabrication of an implant-supported restoration with natural fluorescence. The integration of a high degree of fluorescence is especially important in patients with a high smile line, as presented here, to reduce the so-called umbrella shadowing effect.

**CASE 5**

**Fig 46** Provisional crown restoration at the maxillary left central incisor site.

**Fig 47** Fluorescent zirconia (Zr + Fl) versus regular zirconia abutment (Zr) under UV and natural light.

**Fig 48** Fluorescent zirconia (Zr + Fl) versus regular zirconia abutment (Zr) under UV and natural light.

**Fig 49** Fluorescent zirconia abutment under UV light showing the favorable fluorescent properties.
Fig 50 Preoperative situation.

Fig 51 Definitive alumina crown on the fluorescent zirconia abutment under UV light showing natural fluorescence.

Fig 52 Postoperative view of the definitive alumina crown on the fluorescent zirconia abutment.

Fig 53 Preoperative periapical radiograph.

Fig 54 Preoperative smile.

Fig 55 Postoperative periapical radiograph.

Fig 56 Definitive implant crown.
Some challenging cases may require shaded or more translucent types of zirconia (Prettau Zircona “translucent,” Zirkonzahn) or further coloring of the implant abutment to achieve ideal esthetics. The degree of translucency, however, translates to a lower value and influences the ultimate degree of fluorescence (Figs 57 and 58).

In case 6 (Figs 59 to 76), the maxillary right central incisor was restored with a full-coverage crown, while the maxillary left central incisor was replaced with an implant-supported crown. To achieve an optimal match between the two restorations, the color of the severely destructed maxillary left central abutment tooth must be taken into consideration. In addition to conventional shade tabs (Fig 59), a digital spectrophotometer (Spectroshade, MHT Optical Research, Niederhasli, Switzerland) was used to select the stump shade of the abutment tooth (VITA shade C3, VITA Zahnfabrik, Bad Säckingen, Germany). At first, it was attempted to match the shade of the implant abut-
Fig 61 Translucent zirconia abutment modified with colorant (shade C1) and fluorescence (Tr + C1 + Fl).

Fig 62 Translucent zirconia abutment modified with colorant (shade C1) and fluorescence under UV light (Tr + C1 + Fl). Note the unfavorable fluorescent properties.

Fig 63 Zirconia abutment modified with fluorescence (Zr + Fl).

Fig 64 Zirconia abutment modified with fluorescence (Zr + Fl) under UV light. Note the matching fluorescent properties.

Fig 65 Translucent zirconia abutment modified with colorant (shade C3) and fluorescence (Tr + C3 + Fl).

Fig 66 Translucent zirconia abutment modified with colorant (shade C3) and fluorescence under UV light (Tr + C3 + Fl). While the shade and translucency were favorable, the fluorescent properties did not match the natural teeth.

Fig 67 Provisional restorations on the central incisors.

Fig 68 Intraoral view of the natural abutment tooth (shade C3) versus the fluorescent zirconia abutment (Zr + Fl) under UV light.

Fig 69 Intraoral view of the abutment tooth (shade C3) versus the fluorescent zirconia abutment (Zr + Fl) under natural light.
Fluorescence—Mimicking Nature for Ultimate Esthetics in Implant Dentistry

Fig 70 Preoperative intraoral situation.

Fig 71 Preoperative periapical radiograph.

Fig 72 Postoperative intraoral view of the definitive zirconia crowns under UV light, depicting favorable fluorescent properties.

Fig 73 Postoperative periapical radiograph.

Fig 74 Postoperative intraoral view of the definitive zirconia crowns.

ment with that of the natural abutment tooth. However, Figs 61 to 66 depict the negative effect of the high translucency/low value on the fluorescence. A preferable soft tissue appearance with new provisional restorations (Fig 67) was achieved with an uncolored but fluorescent zirconia abutment (Figs 68 and 69), which matched the fluorescence and value but not necessarily the shade (chroma and hue) and translucency of the natural abutment tooth. Therefore, in such situations, fluorescence/value matching takes priority over translucency/shade matching.

The importance of mimicking natural fluorescence to achieve optimal esthetics in implant dentistry is exemplified in Figs 70 to 76, which compare the initial and postoperative situations.
Fig 75 Preoperative smile.

Fig 76 Postoperative smile.
Fluorescence—Mimicking Nature for Ultimate Esthetics in Implant Dentistry

CRITERIA FOR ZIRCONIA IMPLANT ABUTMENT SELECTION

Zirconia implant abutment selection is based on the following factors:

1. Three-dimensional implant position. The screw-access opening in the abutment should not compromise mechanical strength, and the zirconia should be at least 0.8-mm thick.
2. Soft tissue thickness. A minimum thickness of 3 mm is ideal.
3. Interocclusal space. Sufficient abutment height is required for ultimate resistance.
5. Color of the intended crown restoration (alumina versus zirconia).

The desired marginal preparation of the implant abutment is generally a circumferential chamfer or rounded shoulder to ensure optimal stability and fit of the coping. The margin should be placed deeper on the labial aspect than on the palatal aspect, but no deeper than 1 mm subgingivally. Shallower is actually preferred for postinsertion cement control. Margin location is directly related to the implant depth. However, the implant abutment should be designed to fully support the desired crown contour and soft tissue collar. Ideally, the implant abutment should support 90% of the total surrounding soft tissue contour, while the crown itself should only support about 10%. The integration of fluorescent properties in these areas is key to ultimate esthetic success.

CONCLUSION

In modern prosthetic and implant dentistry, much emphasis is placed on optimal shade and translucency matching for esthetic success. However, a primary optical feature of natural teeth is often overlooked: fluorescence. Because fluorescence is typically the strongest in the gingival third of natural teeth, a lack of fluorescence is most obvious in implant-supported restorations and will negatively influence the surrounding soft tissues. In fact, for ultimate esthetic success, natural fluorescence may take precedence over other optical features, especially at the abutment-crown interface.

REFERENCES
