

TRANSPARENCY IN DETAIL: CERAMIC LAYERING AGAINST PIGMENTATION IN THE CUTTING EDGE AREA

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Summary

The transparency of the incisal edge in the anterior region is a key parameter that determines the visual naturalness and realism of ceramic restorations. Two methods of achieving it are widely used in clinical practice: multilayer ceramic modeling and pigmentation with dyes. However, the choice between these approaches is often made intuitively, without taking into account their optical and long-term characteristics. Objective. To conduct a literature review to substantiate the effectiveness of a multilayer ceramic approach compared to pigmentation in creating a transparent incisal edge in anterior teeth. Materials and methods. A review of scientific publications for the period 2015-2024 on methods of simulating transparency in restorative dentistry was conducted. Results. Literature analysis and clinical observations indicate that layering allows for greater depth, optical naturalness, preservation of light transmission and anatomical reliability of mamelons. Pigmentation with dyes, especially dark shades, in the incisal edge area can create the effect of visual contamination, reducing the aesthetic value of the restoration. Literature analysis confirms that patients visually evaluate layered restorations better, especially on a light background (lower teeth, tongue). Conclusions. It is advisable to reproduce the transparency of the incisal edge using multilayer ceramic modeling with the use of transparent and translucent masses. This approach provides not only a high level of aesthetics, but also the stability of the result from an optical and clinical point of view. Analysis of modern literature sources confirms the feasibility of the advantage of layering over pigmentation in the manufacture of high-quality aesthetic restorations.

Key words: aesthetic dentistry, incisal edge, transparency, layering, pigmentation, mamelons, ceramic restorations.

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1. Introduction

Aesthetic dentistry has undergone a significant transformation in recent decades due to the introduction of high-tech materials and digital restoration modeling protocols. One of the most subtle and at the same time most decisive parameters of a successful anterior restoration is the optical reliability of the incisal edge, which is ensured not only by color matching, but primarily by transparency, the presence of mamelons, opalescent depth and light scattering within the ceramic structure (*Fradeani & Barducci, 2020; ... Petrukha & Petrukha, 2023*). It is the incisal edge area that is most vulnerable to deviations in visual perception, because any deterioration in light transmission or color harmony in this area can instantly disrupt the illusion of naturalness even with overall accuracy of shape and shade. (*Zarone, Russo, Ferrari & Sorrentino, 2023; Magne & So, 2021; Almeida, Faria & Bottino, 2022*).

Despite the obvious role of multi-layer modeling in creating deep and dynamic optical effects, pigmentation methods are still common in clinical practice as an alternative to layering. This approach is often driven by commercial pressures, lack of clinical time, or insufficient training of the dentist and dental technician. (Fradeani & Barducci, 2020; Almeida, Faria & Bottino, 2022; Alghazzawi, Lemons, Salinas & Delgado, 2021). However, surface staining, especially in the area cutting edge, significantly causes a decrease in the level of light transmission through the restorative material, which negatively affects its optical transparency and deep light effect, and creates a risk of visual contamination, particularly when viewed against the background of the lower teeth or tongue (Zarone, Russo, Ferrari & Sorrentino, 2023; Morimoto, Tay & Özcan, 2023; Baratieri, Monteiro & De, 2021; Alghazzawi, Lemons, Salinas & Delgado, 2021).

On the other hand, the multilayer application of transparent, translucent and opalescent ceramic masses allows you to create a reconstruction that imitates the natural stratification of enamel and dentin. This approach allows not only to achieve the visual effect of a "living" tooth, but also to ensure its preservation in dynamics: under different angles of lighting, as well as in motion. (Fradeani & Barducci, 2020; Zarone, Russo, Ferrari & Sorrentino, 2023; Magne & So, 2021; Almeida, Faria & Bottino, 2022).

In view of this, there is an interdisciplinary need to rethink the standards of aesthetic restoration from the perspective of optics, materials science, clinical effectiveness and subjective patient perception. The relevance of the problem also increases in the context of the development of digital technologies, where the accuracy of designs often prevails over the aesthetic result due to imperfect modeling of the cutting zone.

A systematization of modern ideas about the role of incisal edge transparency in the creation of biomimetic restorations has been carried out. and analyzed the effectiveness of two opposing approaches: pigmentation and layering. The results of this study can be applied both in everyday clinical practice and in the development of educational modules for the training of dentists, standardization of laboratory fabrication protocols, and improvement of digital design of restorations.

2. Literature Review

The issue of faithfully reproducing the transparency of the incisal edge of anterior teeth in ceramic restorations occupies a central place in modern aesthetic dentistry, as it determines the optical authenticity of restorations, their lighting characteristics, and harmonious integration into the morpho-aesthetic structure of the smile. (Zarone, Russo, Ferrari & Sorrentino, 2023; Magne & So, 2021; Coachman, Calamita & Sesma, 2022). Over the past two decades, a number of scientific studies have been devoted to this topic, in which an attempt has been made to systematically characterize the optical phenomena inherent in the natural cutting edge, in particular: opalescence, fluorescence and the mamelon effect, and develop methods for their clinical and laboratory reproduction (Fradeani & Barducci, 2020; Zarone, Russo, Ferrari & Sorrentino, 2023; Papadiochou & Pissiotis, 2020).

The research of Magne and Belser (2002, 2018) became the conceptual basis for biomimetic restoration of the anterior dentition (Magne & So, 2021). The authors first proposed using the principle of "anatomical modeling" with differentiation of enamel and dentin masses, reproduction of optical heterogeneity of the natural tooth and creation of a multilayer structure with optical depth control. Similar approaches were developed in the works of Fradeani (2012), who demonstrated the advantages of stratification of translucent and opalescent ceramics compared to single-layer or pigmented techniques (Fradeani & Barducci, 2020).

The study of the influence of the degree of transparency of ceramic materials on the phototechnical characteristics and light transmission ability in aesthetic restorations, as well as their clinical application, was the subject of work by Sulaiman et al. (2019), who showed that the transparency of ceramics significantly affects the subjective perception of shade, depth and “naturalness” of the restoration. These data are also confirmed by other studies that, in addition to optical characteristics, evaluated the stability of color and gloss depending on the thickness and type of material used. (Morimoto, Tay & Özcan, 2023; Almeida, Faria & Bottino, 2022; Alghazzawi, Lemons, Salinas & Delgado, 2021). However, despite the scientific evidence base, pigmentation is often preferred in clinical practice as a faster and less labor-intensive method. This is due to with insufficient level of practical training, and with a lack of clear evidence of long-term clinical advantages of a multilayer approach compared to pigmentation (Fradeani & Barducci, 2020; Almeida, Faria & Bottino, 2022; Alghazzawi, Lemons, Salinas & Delgado, 2021).

A number of authors emphasized that pigmentation is not an anatomical method, but rather an illusion based on optical deception, especially dangerous in transparent areas such as the incisal edge (Morimoto, Tay & Özcan, 2023; Baratieri, Monteiro & De, 2021; Alghazzawi, Lemons, Salinas & Delgado, 2021). Surface application of a dark dye in this area not only blocks the passage of light, but also changes the spectral characteristics of the reflected light, which leads to optical dissonance, especially against the background of the mucous membrane or lower teeth, which are lighter than the enamel structure. (Morimoto, Tay & Özcan, 2023; Baratieri, Monteiro & De, 2021; Alghazzawi, Lemons, Salinas & Delgado, 2021).

Despite the existence of individual experimental studies, there is still no systematic comparison of the results of restorations using pigmentation and multilayer stratification in a controlled clinical protocol (Almeida, Faria & Bottino, 2022; Magne & So, 2023; Papadiochou & Pissiotis, 2020). Most studies focus on the optical properties of the materials themselves in vitro, while the results of real clinical perception by patients, the influence of background, lighting, and anatomical features of the cutting edge remain poorly understood (Almeida, Faria & Bottino, 2022; Magne & So, 2023; Papadiochou & Pissiotis, 2020).

Taking into account fundamental and modern scientific research in the field of aesthetic dentistry, it is appropriate to outline the existence of a scientific gap in the form of an insufficiently highlighted interdisciplinary comparative analysis of the effectiveness of pigmentation and stratification methods precisely in the context of incisal edge modeling, which is critically important for achieving optical authenticity of ceramic restorations (Zarone, Russo, Ferrari & Sorrentino, 2023; Magne & So, 2023; Papadiochou & Pissiotis, 2020). The problem of standardizing methods for reproducing transparency, taking into account the refractive index of materials, layer thickness, base color of the prepared tooth, background lighting, and patient perception, also remains unresolved.

Given the great clinical significance of incisal transparency in the formation of a natural aesthetic effect in frontal ceramic restorations, as well as the lack of standardization of modern approaches to its reproduction, it is important to conduct a comprehensive review of scientific, experimental, and clinical data on the effectiveness of the two most common methods – multilayer ceramic modeling (stratification) and surface pigmentation.

3. Problem Statement

The aim of the study is to: systematize modern sources of literature that highlight the optical features of the incisal edge and their influence on the visual perception of the restoration;

analyze the main advantages and limitations of the multilayer modeling technique in comparison with the methods of pigmenting with paints; characterize the material science and optical parameters that affect the result and stability of restorations in dynamics; present our own clinical observations on the aesthetic perception of restorations made using both approaches; determine clinically oriented criteria for choosing a technique for reproducing transparency in the incisal edge area, taking into account the anatomical situation, background color, and patient wishes.

Solving the tasks set will allow us to deepen the scientific and practical understanding of the mechanisms of achieving optical naturalness in frontal restorations, which will contribute to improving the aesthetic quality, durability and predictability of dental interventions, as well as improving educational programs in the field of aesthetic dentistry.

4. Results and Discussion

The transparency of the incisal edge in the anterior dentition is one of the most important criteria for assessing the aesthetic quality of a ceramic restoration. According to modern research, this area is the most noticeable when a smile is perceived, as it conveys optical depth, transparency, opalescence, and color dynamics when lighting changes (*Zarone, Russo, Ferrari & Sorrentino, 2023; Coachman, Calamita & Sesma, 2022*). Anatomically, the incisal edge is formed by a thin layer of enamel without underlying dentin, which determines its high optical transparency.

Classical studies confirm that the optical properties of enamel are not uniform: they depend on the layer thickness, the degree of mineralization, the presence of prisms and interprism zones, as well as the angle of incidence of light (*Magne & So, 2021*). (Fig. 1).



Fig. 1. Visualization of material transparency during stratified layering on a white and black background for comparative evaluation of optical properties

In order to reproduce this effect in artificial restorations, two main techniques are used: multilayer ceramic modeling (stratification) and pigmentation. In the literature of recent years, there is a clear tendency towards the advantage of stratification as a method that allows achieving not only visual but also structural similarity to natural enamel (*Almeida, Faria & Bottino, 2022; Yilmaz, Johnston & McGlumphy, 2022*). (Table 1).

Table 1

Comparative optical characteristics of stratification and pigmentation

Parameter	Stratification	Pigmentation	Source
Light transmission	High, controlled	Reduced, uncontrolled	Zarone et al., 2023
Optical depth	Three-dimensional, natural	Flat, superficial	Magne et al., 2023
Mamelon effect	Full-fledged, anatomical	Simulated, visual	Fradeani & Barducci, 2020
Color stability	High (long-lasting)	Tendency to loss of pigmentation	Morimoto et al., 2023

Multilayer modeling is based on the use of several types of ceramic masses – opaque, dentin, enamel, transparent, opalescent – which are applied according to the morphology of the natural tooth. This approach allows you to simulate mamelons, intermamellar spaces, a central transparent zone, and peripheral zones of color saturation (*Fradeani & Barducci, 2020*). Stratification provides three-dimensional anatomical correspondence, which is impossible to achieve with two-dimensional pigmentation (*Magne & So, 2021*).

Instead, pigmentation as a method was introduced as a simplified alternative to modeling, mainly for the purpose of rapid color modification (*Morimoto, Tay & Özcan, 2023; Baratieri, Monteiro & De, 2021*). Current reviews indicate that pigmentation in the transparent area of the incisal edge, especially with dark dyes, causes optical obscuration, reduced transparency, and the risk of a visual “soil” effect, which is especially pronounced against the background of the mucous membrane or tongue (*Morimoto, Tay & Özcan, 2023; Alghazzawi, Lemons, Salinas & Delgado, 2021*). In addition, dyes tend to lose pigmentation and reduce color stability under the influence of cyclic temperature stress (*Almeida, Faria & Bottino, 2022*).

Zarone Research and al. (2023) found that pigmented restorations have a 22% lower light transmission coefficient compared to stratified restorations at the same layer thickness. This effect is even more pronounced when using stains with metallic components (*Zarone, Russo, Ferrari & Sorrentino, 2023*). According to the study by Almeida et al. (2022), with a thickness of transparent enamel mass of 0.7 mm without pigmentation, maximum natural optical correspondence is achieved, while with pigmentation of the same area, a “smoothing” effect and loss of mamelon differentiation are observed (*Almeida, Faria & Bottino, 2022*).

Some sources indicate that pigmentation may be useful as an adjunctive technique to highlight fissures or cervical areas, but not to create a clear incisal edge (*Baratieri, Monteiro & De, 2021; Coachman, Calamita & Sesma, 2022*). According to a systematic review by Magne and al. (2023), 87% of clinically successful restorations with high aesthetic scores used a layering technique, while pigmented restorations were more likely to have complaints of an “artificial appearance” (Table 2) (*Magne & So, 2023*).

Table 2

Impact of technology on clinical aesthetics according to reviews (2020–2024)

Authors	Method	Aesthetic rating (0–10)	Features
Almeida et al., 2022	Layering	9.2	High naturalness, depth effect
Morimoto et al., 2023	Pigmentation	6.8	Lost transparency in the cutting area
Zarone et al., 2023	Layering	9.5	Realistic rendition of opalescence
Baratieri et al., 2021	Pigmentation	7.1	Pigments block light against the background of the tongue

It is important to emphasize that the stratification technique provides an individualized approach to reproducing the optical characteristics of the restoration, taking into account the patient's morphology – in particular, the thickness of the natural enamel, the color of the dentin, and the degree of translucency of the adjacent teeth. Pigmentation, in most cases, does not take into account the three-dimensionality of the structure and is applied superficially or in a uniform layer, which leads to a visually “flat” restoration (*Papadiochou & Pissiotis, 2020*).

In the context of digital dentistry, pigmentation also loses its significance. When creating digital restoration designs (DSD 3.0, Exocad), the incisal edge is modeled taking into account the optical characteristics of the ceramic, and pigmentation is not provided as a visualization tool. This is also confirmed by the experience of Coachman et al. (2022), who indicate that digital simulation of translucency is possible only in the case of stratified construction (*Coachman, Calamita & Sesma, 2022*).

Therefore, the analysis of the current literature demonstrates the clear dominance of the multilayer approach as a clinically effective, optically sound, and aesthetically acceptable method for reproducing a clear incisal edge. Pigmentation can be used as an adjunct, but should not replace stratification in optically sensitive areas.

Thus, a review of modern literature confirms that the transparency of the cutting edge is a critically important factor in achieving high aesthetic quality of restorations in the anterior region. A comparative analysis of scientific sources from 2020–2024 indicates the undeniable advantage of multilayer ceramic modeling (stratification) over pigmentation in the formation of a natural optical effect.

5. Conclusions

1. Layering provides not only anatomical but also optical authenticity through the use of variable masses with different levels of transparency, fluorescence, and opalescence.
2. Pigmentation of the cutting edge, especially with dark dyes, leads to loss of light transmission, creates the effect of visual darkening and impairs depth perception.
3. According to published studies, the aesthetic evaluation of restorations with stratification significantly exceeds similar indicators for pigmented restorations (by 20–30%).
4. Pigmentation can only be used as an auxiliary tool in other areas – cervical, approximal or fissure, but not in the incisal area.

Thus, when planning restorations of the anterior group of teeth, preference should be given to a multilayer technique with individual selection of masses, taking into account the optical characteristics of the patient's natural teeth. This allows achieving maximum naturalness, stability of the result and patient satisfaction .

6. Prospects for further research

Despite the availability of a sufficient number of clinical and laboratory studies, in the field of aesthetic modeling of the incisal edge, there are unresolved issues that require further study: the need to develop standardized stratification protocols taking into account anatomical morphology and transparency for different age groups and enamel phototypes; further study of the influence of the thickness and location of individual masses on optical effects in dynamics – under different lighting, viewing angle and background color (mucous membrane, tongue); development of digital algorithms for predicting the transparency of the incisal edge at the diagnostic stage using CAD / CAM technologies; comparative studies of long-term clinical results of restorations with pigmentation and stratification in the context of color stability, optical transparency and biocompatibility; Further interdisciplinary research combining optical physics, materials science, digital diagnostics, and clinical practice will contribute to improving approaches to modeling the transparent incisal edge and forming new standards in aesthetic dentistry.

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