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EDITORIAL

WILEY

Advances in Esthetic Dentistry 2023

Dear Colleagues,

We take great pleasure to present our annual special issue of *Advances in Esthetic Dentistry 2023* as part of the Journal of Esthetic and Restorative Dentistry (JERD). Since its inception in 2021, this special issue has become a true reference library of the top clinical/case reports, research, and review papers in esthetic dentistry. Articles featured in *Advances in Esthetic Dentistry* 2022 have been downloaded a stunning 52,000 times in the single year, exceeding 2160 downloads per paper, and 6140 for the most downloaded paper. Building on this past success, our goal for the current issue was to provide another inspiring update of contemporary esthetic dentistry while pushing the boundaries of interdisciplinary esthetic excellence in everyday clinical practice. In addition, we remain committed to bridging the gap that can exist between clinicians, researchers, and dental technicians, providing scientific evidence for clinical treatment.

The interest in esthetic dentistry remains at the forefront of dentistry. The fact that JERD content is comprehensive and inclusive of all specialties makes it the perfect medium for thorough update in the dynamic field of esthetic dentistry. The advantages and benefits for dental professionals are best illustrated by the variety of subjects in this issue. It contains a total of 27 articles including 11 clinical, 9 research, and 7 review articles with 298 pages and 581 images. Although the content to a large extent transcends beyond individual disciplines and topics, based on the predominant ones, it is divided into the following sections: restorative dentistry, prosthodontics, periodontics, implant dentistry, digital dentistry, and orthodontics.

The vastly illustrated clinical technique articles and case reports offer a wide variety of information on significant changes in interdisciplinary dental treatment as well as new technologies or practical approaches to recognized clinical challenges. The featured research and review papers provide much-needed scientific evidence on current and up-and-coming techniques and technologies in the field, providing valuable tools for treatment planning and clinical decision-making.

Authors for *Advances in Esthetic Dentistry* 2023 were invited based on their international reputation and prominence in esthetic dentistry. We also extend a special thank you to all co-authors for their valuable contributions. Each new issue of *Advances in Esthetic Dentistry* offers up-to-date, evidence-based information, pertinent to the integration of dental esthetics into oral health care, from general to highly specialized and interdisciplinary topics.

Another important factor that greatly contributed to the quality of this issue, is strong and timely support from the Wiley's editorial team. This includes but is not limited to Sindhu Varghese, Reeni Sunder, Zora Ma, Karen Harmon and Wiley's wonderful editors, Meg Crawford and Rosie Hutchinson.

We trust that you will find many 'pearls' in this issue that may help elevate your work in your office or laboratory to the next level. To continue the successful path of *Advances in Esthetic Dentistry*, we invite you to make this a collaborative effort. Please send your comments and suggestions, including topics of interest, to jerd_advances@wiley.com. We thank you for your great and continued support. Enjoy the 2023 issue of *Advances in Esthetic Dentistry!*

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CLINICAL ARTICLE

Nature-mimicking layering with composite resins through a bio-inspired analysis: 25 years of the polychromatic technique

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Abstract

Objectives: For decades, the dental community has discussed which materials would be the ideal substitutes for lost tooth structure. Initially, the biomimetic approach advocated that feldspathic ceramics would be the material of choice for enamel. However, given the complexity of obtaining excellent dental technicians and the financial cost, are composite resins a suitable replacement? The optical properties with opalescence and fluorescence effects, as well as this material's high fracture toughness, indicate it as a long-lasting restorative material. However, because this material depends on the operator's expertise, knowledge of layering techniques and the selection of each material for the different layers is required. Thus, knowledge of the polychromatic technique through a bioinspired approach is necessary to obtain results of life-like restorations. This article aims to review the polychromatic layering technique (PLT), considering the optical and mechanical properties of dentin and enamel and correlating these properties with current composite resins to guide clinicians in selecting the most suitable restoratives for their clinical challenges.

Clinical Considerations: The polychromatic layering technique is revisited, cross-referencing the properties of dentin and enamel with current composite resin restoratives and their biomimetic properties. The effectiveness and predictability of the PLT are corroborated in clinical cases of varying degrees of difficulty requiring different layering strategies.

Conclusion: After the bio-inspired analysis, using nature as a model to be understood and followed, it is possible to note how the polychromatic technique remains current and viable in mimicking nature, providing esthetic and natural results in the layering of composite resins.

Clinical Significance: Composite resins effectively replicate the optical and mechanical characteristics of natural dentin and enamel through the bioinspired approach presented by the polychromatic layering technique.

KEYWORDS
bioinspiration, biomimetic, composite layering, dental tissues, light propagation

1 | INTRODUCTION

Restorative dentistry, for decades, has been looking for materials and techniques to replace the tooth structure affected by injuries. In the research of developments for new products, countless alternatives are presented with the promise of being ideal substitutes. As a result, the industry has periodically introduced restoratives combining optimal mechanical and nature-mimicking properties. In addition, numerous in vitro and in vivo studies have scrutinized materials and methods to establish scientific and clinical grounds for consistently creating restorations that emulate dental tissues.[1–5]

Skilled ceramists use elaborate stacking techniques to artistically achieve high-quality results that mimic the living tissues (Figure 1). In the same way, composite layering techniques have been introduced with significant clinical acceptance and application, aiming at the quest for restorations that go unnoticed by the most attentive observer[6–8] (Figure 2A,B).

The clinician's critical challenge has consistently been producing restorations that mingle natural tissues' characteristics with synthetic restoratives according to biomimetic principles. Biomimetics is an interdisciplinary field in which principles from engineering, chemistry, and biology are applied to the synthesis of materials, synthetic systems, or machines that have functions that mimic biological processes.

In this scenario, ceramics are considered the materials closest to dental structures by the biomimetic dental school of thought—feldspathic porcelain, particularly—as they closely emulate dental enamel's mechanical and optical characteristics.[9] Because enamel is very similar to glass due to its high mineral content, the calcium phosphate crystals (hydroxyapatite) and other constituent minerals of this acellular layer give it an anisotropic behavior and a light dispersion like that found in porcelain[10] (Figure 3A–D). However, the definition of an ideal synthetic substitute can only be defended with deeper pondering. Porcelain is credited with being more abrasive to opposing enamel than composite resins. Additionally, its manufacturing technique also requires more invasive tooth preparations and a more complex and costly workflow due to the increased time and cost of the laboratory process.

Although immersing in materials science per se seems fascinating, the choice of a substitute synthetic material prompts reasoning that extends beyond mechanical and optical properties found in biomimetics to consider the overall scope of restorative dentistry as a field of health promotion.

Whether with resins or ceramics, the restorative process depends on the technical skill of the human being; in other words, it is operator-dependent.[11] However, ceramic works are more expensive and depend on an experienced ceramist who, in most cases, is not the dentist himself. Thus, the purpose of this article is to carry out a conceptual analysis not only through biomimetics but through the broader look of bioinspiration for the choice of materials and techniques that can be introduced more simply in the daily lives of clinicians. Furthermore, this article aims at understanding the natural tissues and the characteristics of currently available composite restoratives while scrutinizing and revisiting a logical pathway for their selection and application according to a widely accepted technique published by one of the authors in 1995—*the polychromatic layering technique*.[12]

FIGURE 1 Single unit ceramic crown on maxillary left central incisor.

FIGURE 2 (A and B) Single unit composite restoration on maxillary right central incisor.

2 | THE CHOICE OF COMPOSITE RESIN AS A RESTORING MATERIAL

In many countries, academic discussions argue about the best restorative material when comparing composites versus ceramics. Often

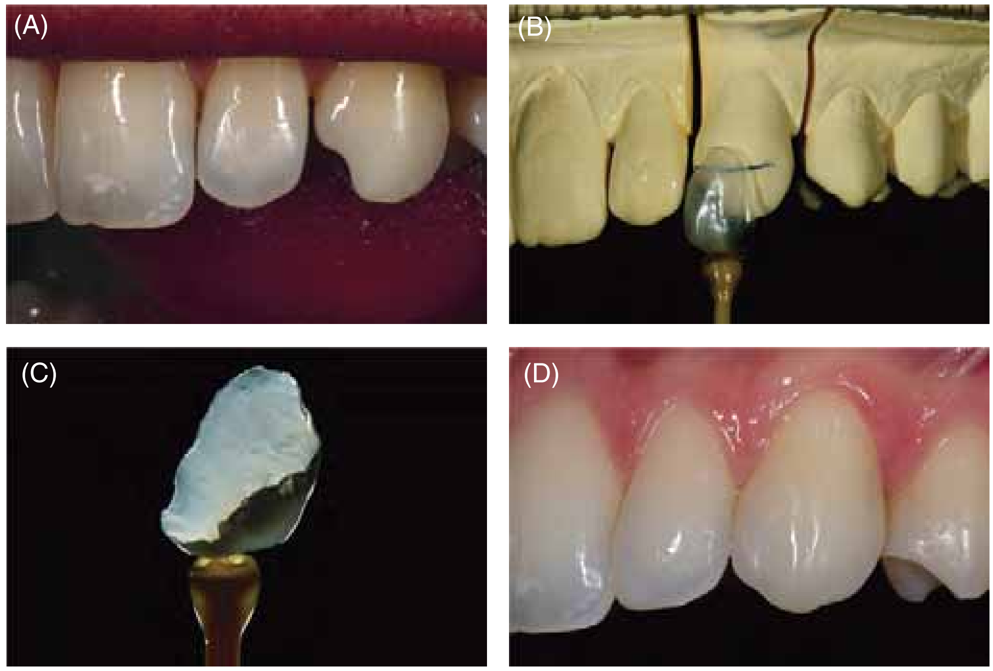

FIGURE 3 (A–D) Add-on feldspathic ceramic contact-lens type fragment.

defended even passionately, this analysis makes no sense when the focus is on the patient. Longevity studies demonstrate that both materials can be used successfully in dental restoration for decades, benefiting people in terms of esthetics and function.[11,13] Mechanically, the physical properties of composite resins have historically been optimized by the often ceramic filler particles of this composite (hybrid) material. With this, a perfect balance can be obtained in the proportion of the organic and inorganic components. In this way, even with simple layering techniques using a single shade and opacity, esthetic and functional results can be achieved with resins, unlike ceramics, which invariably depend on complex implementation techniques (Figure 4A–C).

Another favorable factor for using composite resins is their additive application technique. Because composite resins are directly applied in the mouth, creating a path of insertion, as in the case of indirect restorations, is unnecessary. This direct approach implies more significant preservation of healthy dental structures, keeping Contemporary Dentistry in an additive and not amputative era.[14]

Finally, the high operational cost of ceramic works and the need for an outsourced laboratory service—only sometimes readily available across different countries and their socioeconomic realities—make resins an attractive proposal that places the clinician as the protagonist of a successful esthetic/functional restoration.

3 | THE NATURAL TOOTH IN THE CONTEXT OF BIOINSPIRATION

Dental biomimetics is a concept that seeks to imitate the structure to be restored in the choice of replacement materials.[15] With this, the natural element is studied, and substitutes of similar characteristics are selected whenever eligible. However, when dealing with living beings, this may be a challenging task. Plain logic indicates that the best substitute for enamel should be tissue-engineered enamel itself. Without this possibility, a deep study of the element to be copied must be done, and the search for how to restore it can have a deeper meaning when nature is analyzed more broadly. Bioinspiration analyzes the target element and looks for other forms of intelligent design present in nature (Figure 5). For example, suppose the tooth presents a dentin/enamel junction with a stable and long-lasting chemical and micromechanical bond. Why can adhesives not be produced by studying glues synthesized by mussels that can attach them to the mineral content of rocks even when submerged in water?[16] Dental bioinspiration seeks answers in nature to restore nature itself when damaged. Thus, it does not focus only on the target element but analyzes beings from other specimens and classes to offer viable repair alternatives. However, like biomimetics, studies should always be initiated by the natural object, which is the focus of the copying process.

3.1 | The enamel

This acellular tissue is the hardest in the human body. Its formulation and formatting are intriguing. Its chemical base is mineral, consisting of approximately 95% calcium phosphate and 5% organic matter, which gives it high resistance to friction, demonstrated through tribology analysis.[17] However, it has little ability to withstand plastic deformation before fracture. So, this is a tissue of low fracture toughness. Toughness is the ability of a material to resist crack propagation. Despite the sigmoid prisms arrangement and the presence of proteins associated with a combination of diversely oriented prims in the interprismatic area, its fracture toughness is about four times lower than that of dentin[18] (Figure 6). Thus, the primary function of this outer layer that covers the tooth is to be a protective barrier to the

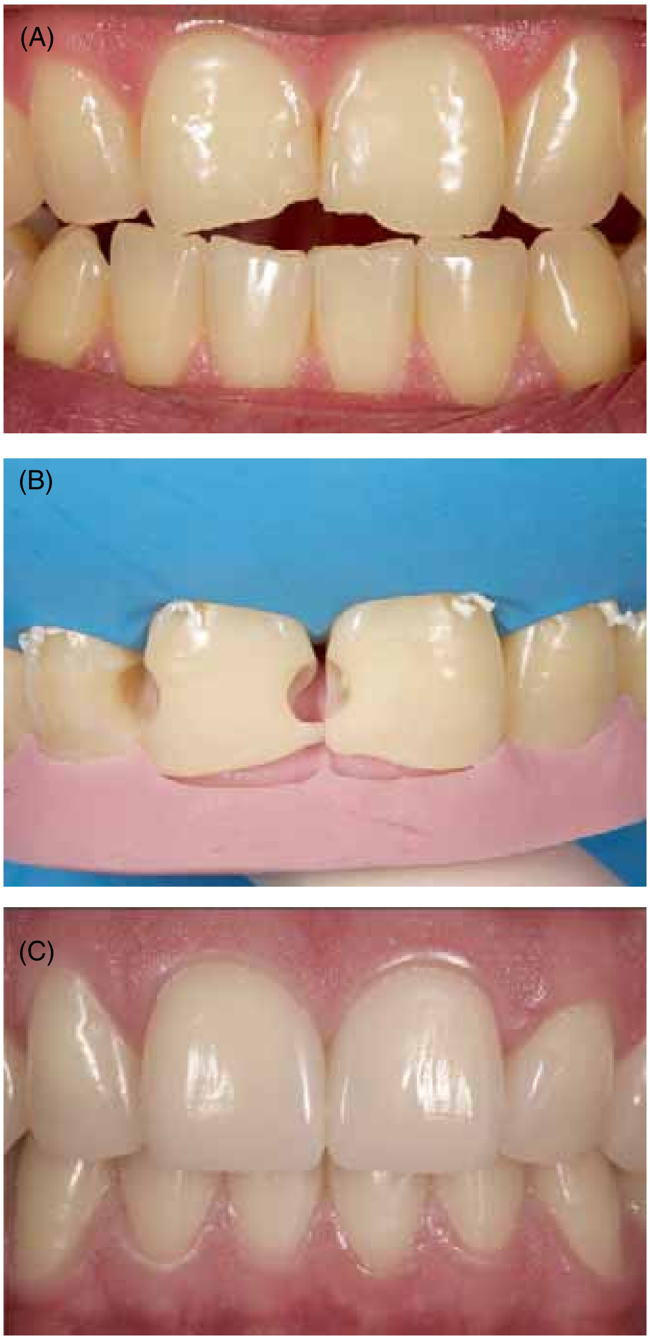

FIGURE 4 (A–C) Monochromatic composite resin restoration showing excellent esthetic results.

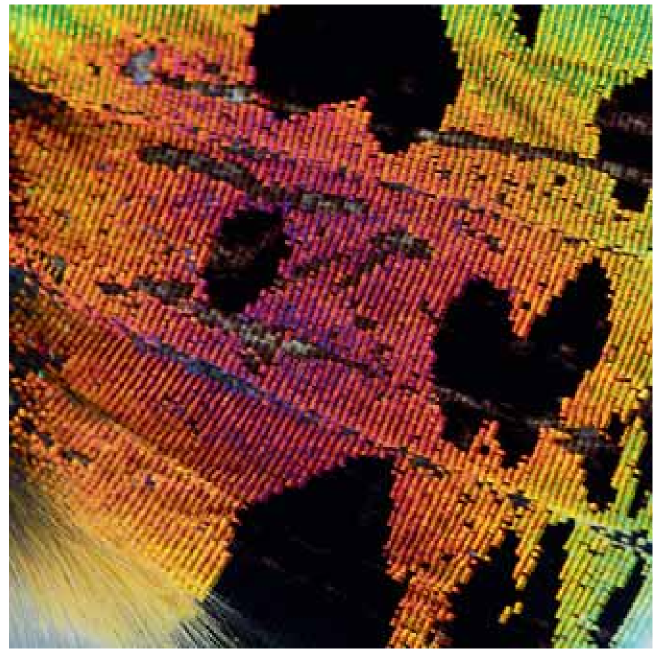

FIGURE 5 Bioinspiration example. Study of the wing of a butterfly to produce lenses and even cosmetics with an unrivaled light dispersion.

FIGURE 6 Enamel cracks demonstrating its low fracture toughness.

underlying cell layers, allowing masticatory efficiency due to coronal rigidity and protecting the dental organ from wear over a lifetime of occlusal service. The organized morphological aspect of this tissue grants it an anisotropy, not behaving equally depending on the direction of the applied load.

An essential aspect of the optical context of this layer is the molecular weight of hydroxyapatite, which is 502 g/mol with an approximate size of 20–70 nm. Despite being a birefringent structure, its average refractive index is 1.63.[19] The light scattering on this substrate will be of the Rayleigh type.[20] The small size of the mineral molecules that compose it will scatter the light with a wavelength of a bluish appearance. The wavelength of visible light is between 400 and 700 nm. If the size of the particles that make up an object is greater than the wavelength, the light does not decompose into its chromatic components. All wavelengths are equally dispersed, which is why it is seen as white when passing through a cloud. When the components are smaller, the light assumes a predominance of blue. For compositions greater than one-tenth of the wavelength, the scattering described as Mie will occur, where blue is no longer predominant, yellow and red becoming more evident. This physical phenomenon makes it possible to explain the opalescent effect in enamel. The

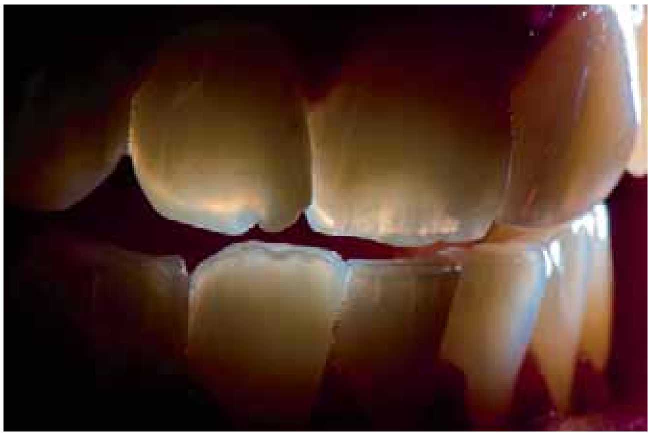

FIGURE 7 Opalescent effect.

FIGURE 8 Enamel cracks barred in dentin.

FIGURE 9 Dentin yellow color.

incident light demonstrates the blue in this layer. On the other hand, the reflected light will present an orange tone since the blue scattering has already occurred during the passage of light inside the enamel (Figure 7).

3.2 | The dentin

Dentin is the tissue that presents a mixture of organic and inorganic components in a balanced way to promote fracture resistance. About 70% of this tissue is of mineral origin (calcium phosphate), and 18% comprises collagen fibrils. This organic material has high resistance to plastic deformation, making dentin approximately 10× more resistant to bending than enamel. This behavior is due to an intriguing network formed by collagen types I, III, and V. Due to this more elastic characteristic, dentin offers high resistance to crack propagation (high fracture toughness).[18] As a result, the cracks formed in the enamel will lose energy as they pass through the junction and reach the dentin (Figure 8). The directional behavior of the load is complex in dentin. The peritubular region presents isotropic behavior, and the orientation of the tubules shows probable isotropy.[21]

The optics of this tissue is related to collagen molecular weight of approximately 300,000 g/mol and size between 180 and 280 nm; the intertwining of fibrils creates collagen networks with sizes in μm. The refractive index is 1.54. In this context, Mie-type scattering will occur, as previously mentioned. This higher molecular weight of the dentin components will not allow the sensation of the blue hue but the visualization of the reddish-yellow hue (brown), which explains the tones of group A of the Vita Classical shade guide as the most frequently found in dentin[22] (Figure 9). It should also be noted that this increased amount of protein creates an effect called fluorescence in this substrate, which is more intense in areas close to the dentin/enamel junction than close to the pulp. With age, the deposition of higher mineral content as secondary and tertiary dentin will decrease this effect[23] (Figures 10 and 11).

4 | BIOINSPIRED ANALYSIS

When the target element (the natural tooth) is studied, it becomes apparent that enamel and dentin are tissues with very different physical (mechanical and optical) behaviors. Despite the similarity in its primordial constitution, dentin resists fracture, presenting a greater optical density and a perception of warmer tones of the visible light spectrum. Enamel, on the other hand, has the function of resisting

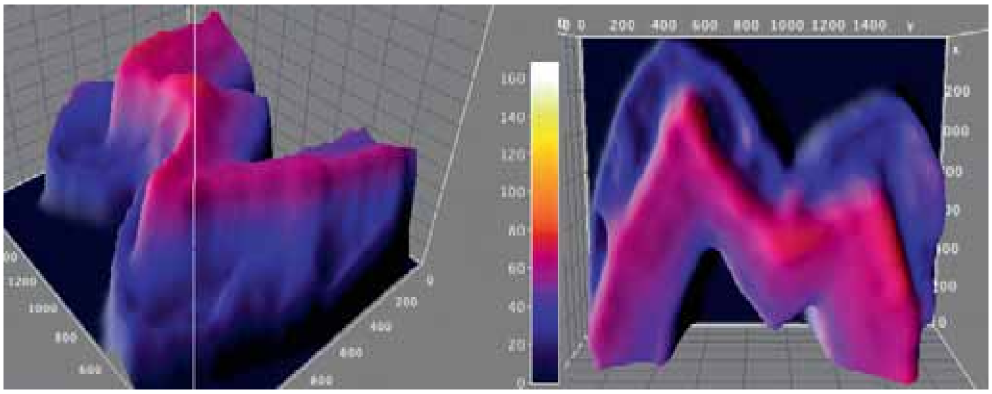

FIGURE 10 Tooth crown fluorescence 3D chart. Note how the effect is more intense from JED to the pulp.

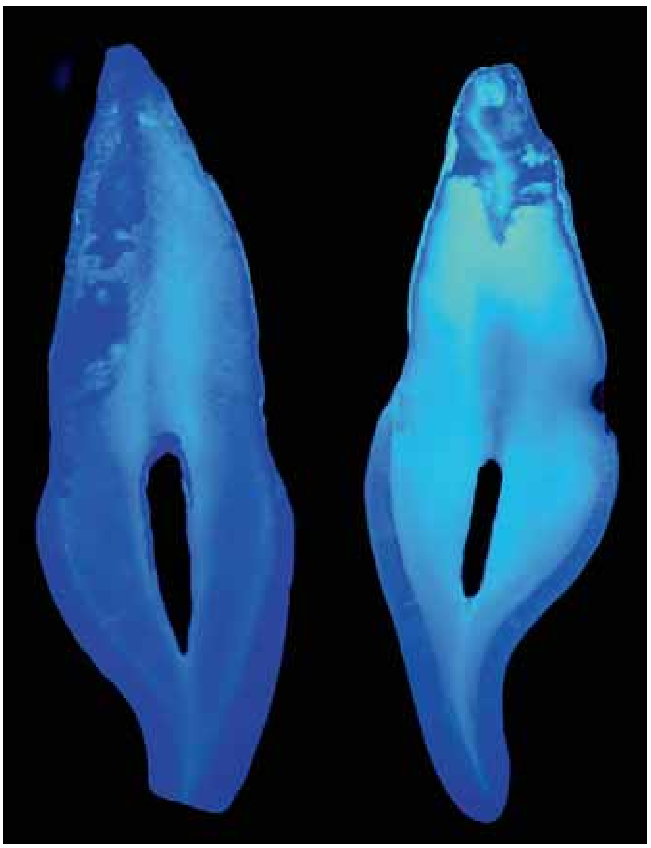

FIGURE 11 Comparison of fluorescence between old (left) and young (right) teeth.

attrition and increasing masticatory efficiency through coronal rigidity, scattering cooler shades of visible color. Within a biomimetic concept, considering the restorative materials currently present in dental practice, resins would be substitutes for dentin, while feldspathic ceramics would be substitutes for enamel. However, despite natural dentin having low wear resistance and natural enamel having low fracture resistance and low toughness, studies of hybrid systems help us to understand that in bioinspiration, an intermediate design model could supply the structural loss of these two materials with only a single restorative material. We have examples of natural bone composites, dentin, and even wood. The latter present specimens with hardness compared to metals depending on the direction and constitution of their fibers. They may also undergo industrial transformations creating materials of very high density and resistance.[24] In this scenario, when dental hybrid composites are processed to balance their organic and inorganic phases, materials can be produced with superior mechanical characteristics. An increase in density can be obtained by balancing different sizes and compositions of the inorganic phase and improving properties and bonds in the organic mesh. Historically, the first composite resins had low abrasive resistance. The modification in the size and composition of the loads provided materials with high resistance to fracture and wear. Studies show composite resins behave like enamel when annual wear rates are verified in vivo.[25]

Moreover, their flexural strength and elasticity bring them closer to the mechanical characteristics of natural dentin. With this, a composite resin can be categorized as a unique replacement for lost tooth structure, fulfilling the mechanical strength role of dentin and the abrasive strength role of enamel. On the other hand, their fragility lies in the potential of longitudinal chemical instability since these materials present a leaching process by hydrolytic degradation in water.[26] However, advances in light curing devices, especially formulations with industrial conversion (prefabricated CAD/CAM blocks), tend to improve the chemical stability of this material.

5 | THE CHOICE OF COMPOSITE RESIN AS A SINGLE SUBSTITUTION MATERIAL FOR LOST NATURAL TISSUE AND ITS MECHANICAL AND OPTICAL INTERACTIONS

5.1 | Mechanics

Even though composite resins have very similar base formulations, their mechanical behavior can vary dramatically depending on brand names due to the different uses of filler particles. This approach is so impactful that the current ranking factor for resins is particle size.[27] Two factors must be considered in this analysis. (1) Particles at the nanometer scale present an industrial deficiency in the silanization process, compromising the mechanical properties of these materials. For this reason, fillers smaller than 50 nm were grouped into clusters patented for a specific brand of resin (Figure 12) (Filtek Supreme

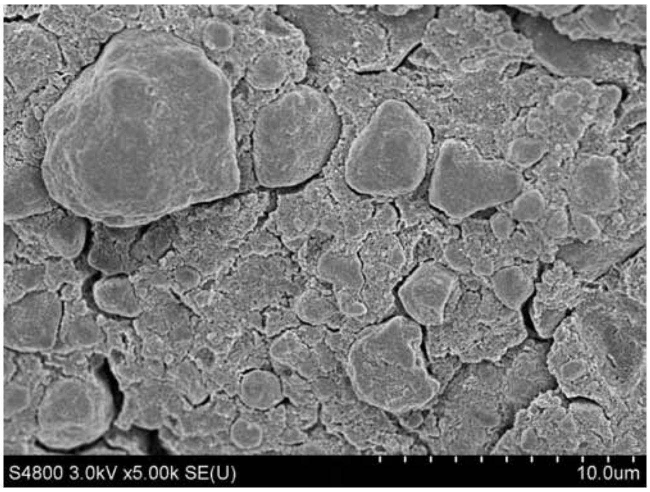

FIGURE 12 SEM of a nanofill clustered composite resin. Courtesy: Marcos Vargas.

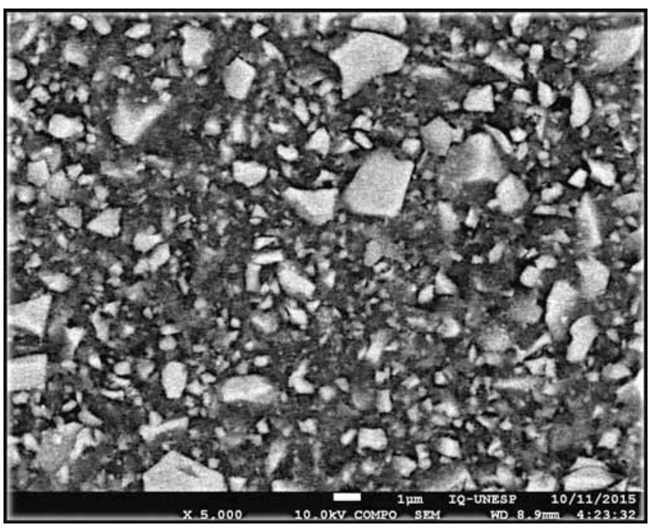

FIGURE 13 SEM of a nanohybrid composite resin.

Ultra, 3 M, Minnesota, USA). (2) Large particles considerably increase the fracture resistance but reduce the wear resistance, the polish, and, to a lesser degree, the flexural strength, which could be improved by increasing the small particle content of the organic phase.[28] Therefore, as the portion that will reconstitute dentin and enamel has different individual characteristics, it would be more logical to choose materials with different constitutions for each layer. The innermost portion of a resin buildup represents the structural reinforcement designated by natural dentin. In this constitutive layer of the restorative core, resins with high mechanical properties, especially fracture toughness, should be chosen. On the other hand, the outer layers need a smoothness provided by polishing, avoiding increased biofilm retention, improving chromatic stability, and high wear resistance.

5.2 | Optics

Following the principles of light scattering in natural teeth, the dentin layer has higher density and, therefore, Mie-type scattering, emphasizing reddish-yellow hues.[20] Thus, most studies analyzing the natural color of dentin indicate a high predominance of the hue of Group A on the Vita shade designation, as mentioned above. This phenomenon occurs when light is scattered in particles larger than 450 nm, increasing the chromatic effect of longer wavelength colors. However, particles with sizes within the visible light spectrum must be present for light decomposition in the material to occur. By this analysis, resins with characteristics suitable for dentin should contain particles ranging from nanometer to micrometer scale, with a predominance of medium-sized than micro or nanoparticles (Figure 13). This concentration will give the dentin layer a higher optical density, making it more opaque. This phenomenon happens in the natural model. However, it suffers variations according to a greater or lesser degree of dentin mineralization in the different areas of the crown and aging. Thus, the dentin will become more opaque from the cervical to the incisal third and from the outermost area to the area closest to the pulp (Figure 14A,B). With aging and increasing mineralization of the dentin structure,[29] fluorescence and opacity will decrease due to protein loss,

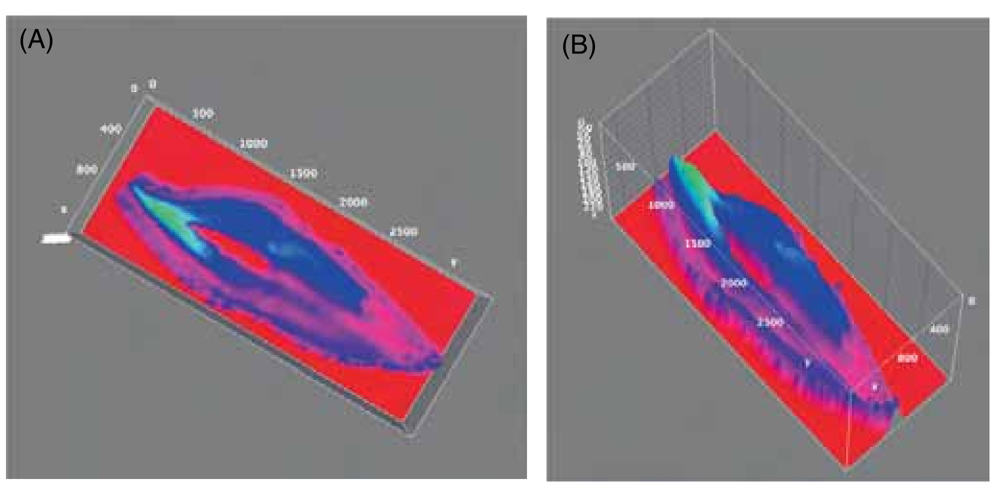

FIGURE 14 (A and B) Tooth crown opacity 3D chart. Green area is the most opaque part, follow by blue tones (medium opaque) and pink (transluscent area).

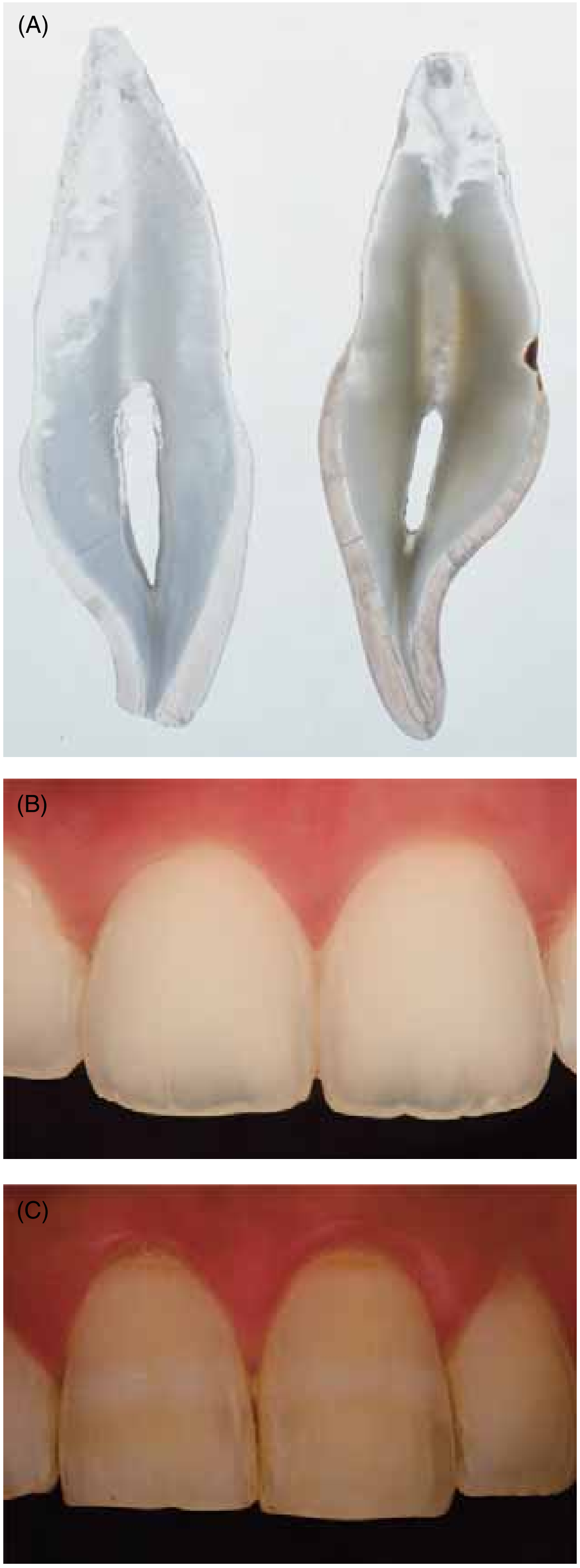

FIGURE 15 Comparison of opacity by age. (A) Extracted teeth (photographed with transmitted light) of older adult (left) and young (right). The older tooth is more translucent. Young and aged teeth show distinct opacity/translucency levels. (B) The young tooth is brighter. (C) The older tooth lost the luminosity.

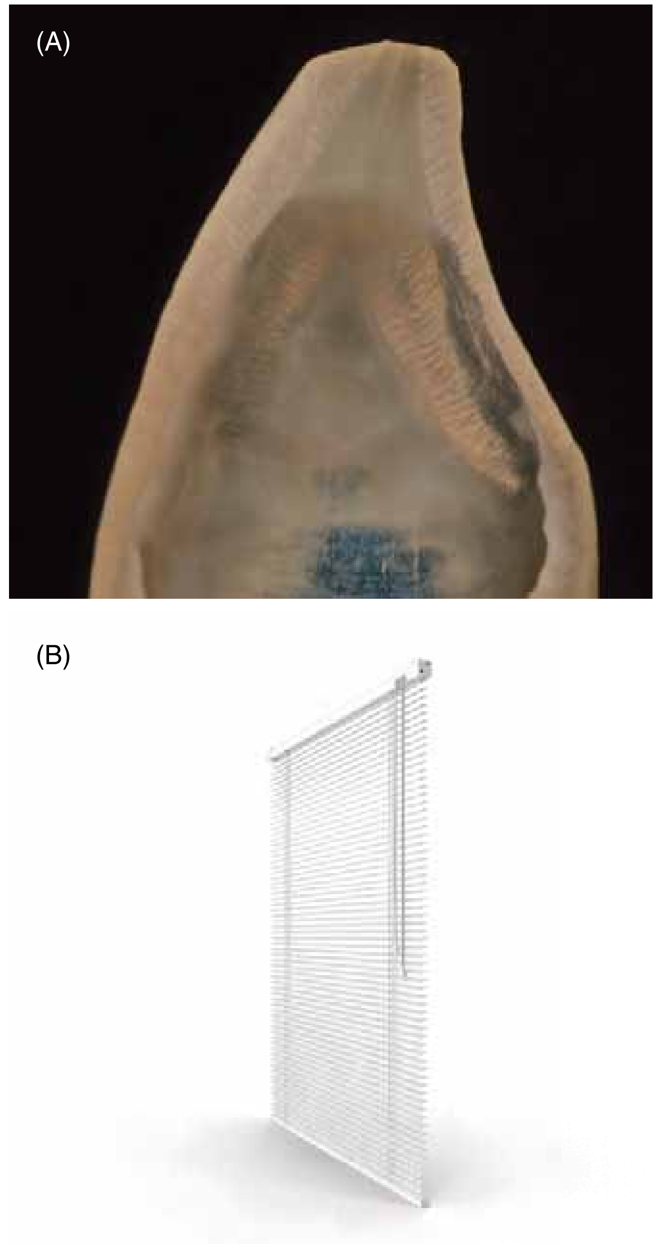

FIGURE 16 (A and B) Images demonstrating the translucent and opaque enamel lamellae and the blind analogy.

making the aged tooth more translucent in the dentin layer. It will also become less reflective of visible light, generating a grayish appearance of low luminosity (Figure 15A–C).

When the enamel is analyzed, a curious situation can be noticed. Enamel is not a translucent material as commonly advocated by clinicians. Instead, it presents an organized arrangement of opaque and highly translucent lamellae in horizontal layers to the crown—when viewed from a facial perspective—compared analogously to a partially open blind. Therefore, the enamel will function as an optical fiber in the hypermineralized prismatic lines capturing the color of the dentin underneath. In addition, the enamel will have a highly opaque behavior in the protein-rich interprismatic areas (Figure 16A,B). If this were not, the tooth would seem bluish even in the face of warmer dentin

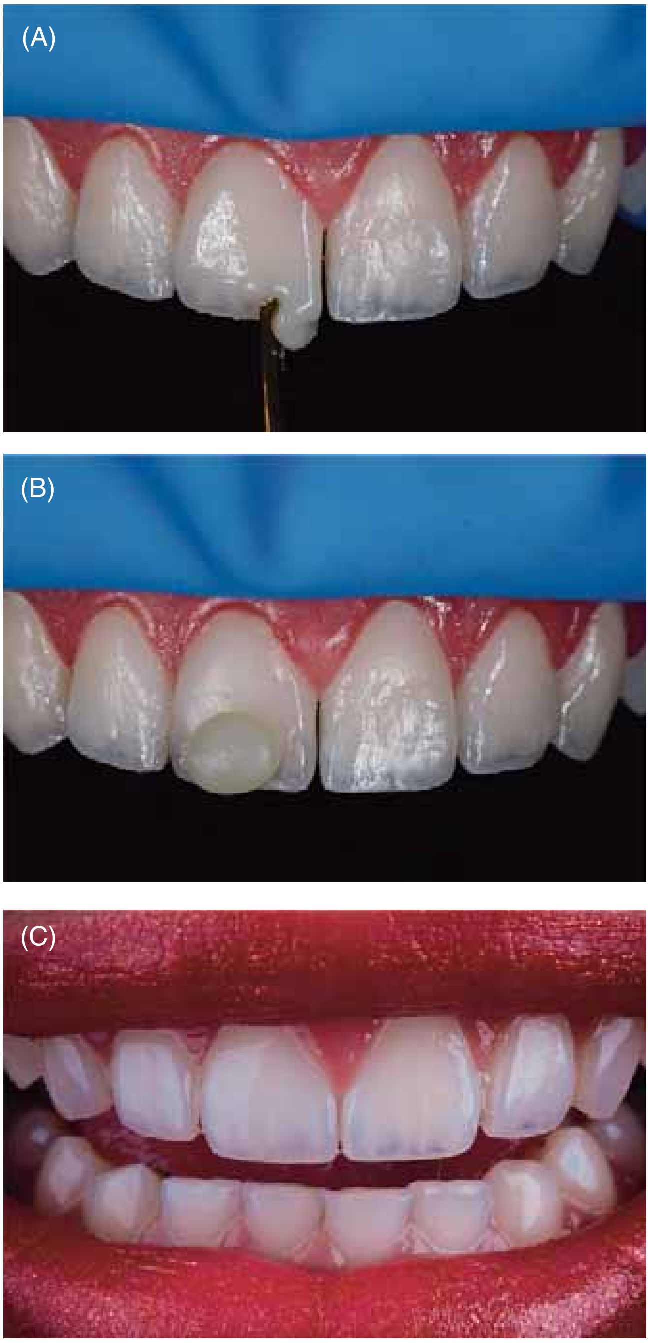

FIGURE 17 (A–C) Cutback being performed and a value-modifying achromatic composite resin layer applied. Post-operatory result.

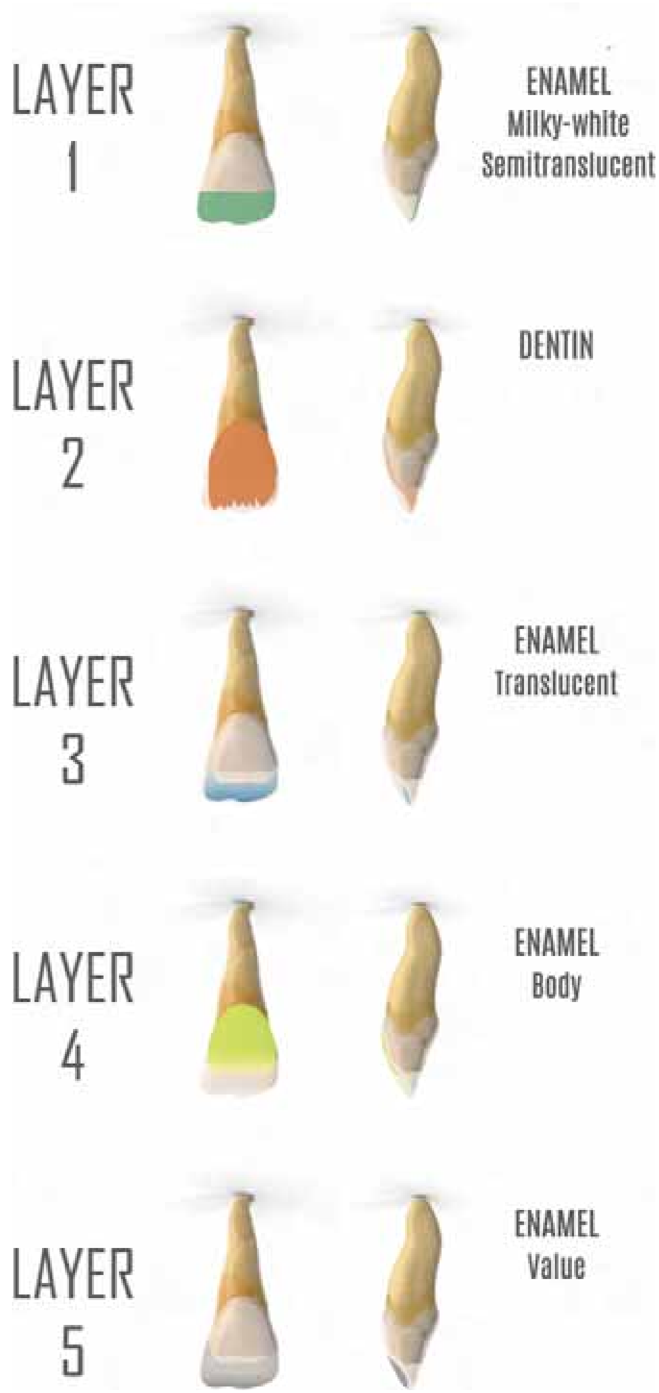

FIGURE 18 Layering diagram in the polychromatic layering technique.

colors. This constitution explains the enhanced light reflection in young patients due to the thicker layer of this tissue. Abrasion and attrition decrease this characteristic with age, making the enamel more translucent overall and exacerbating the teeth' low luminosity with aging. Another essential factor is that composite resins cannot perfectly reproduce this unique characteristic because the material does not present an organized distribution of phases. The latter is one of the factors that most corroborates the naturalness of the polychromatic technique compared to other techniques described in the literature. A single layer of enamel with only one opacity will only be able to reproduce some of the nuances of opacity and translucency visible along the crown. Therefore, enamel shades of higher opacity, that is, higher value, should be used in the middle third area, giving high luminosity to this region, especially in young patients. However, a cutback and the use of enamel shades that reproduce the optical aspect produced by the junction of the buccal and palatal translucent lamellae will provide adequate luminosity and a natural appearance to the restoration (Figure 17A–C). For this purpose, inner opalescent and external resin masses of varying opacities are recommended.

6 | SELECTION OF COMPOSITE RESIN BRANDS FOR THE DIFFERENT AREAS OF THE POLYCHROMATIC TECHNIQUE

Initially described by one of the authors of this article, the polychromatic layering technique (PLT) is based on the rationally organized distribution of five layers that reproduce the optical characteristics of the natural tooth. The conceptual diagramming of the arrangement of the layers by the polychromatic technique is represented in Figure 18.

7 | LAYERS IN THE POLYCHROMATIC TECHNIQUE

Layer 1: In this palatal/lingual layer, the resin must elicit high abrasion/attrition resistance, as it is the path for anterior and canine guidance. High fracture toughness is also required, significantly increasing the resistance of this area to functional loads. As it is a region that challenges the reproduction of natural enamel, the material must have a milky-white semitranslucent characteristic. The milky-white halo along the incisal edge and the bluish opalescent halo internally to it can be achieved by adjusting the thickness of this milky-white semitranslucent layer to allow optical changes. The choice should fall on micro-hybrid and nano-hybrid materials whose particle size composition encompasses nanometric and micrometric scales. The significant filler size variation will allow the correct scattering of light and dispersion into blue wavelengths when these types of particles are present. Thus, variations between 20 and 180 nm (blue effect) and particles within the visible light spectrum will favor natural optics, high fracture toughness, and abrasive resistance.

Layer 2: This is the core layer, the most important for the fracture resistance of the tooth/restoration compound. Because it is an inner layer, fracture toughness is far more critical than wear resistance. This layer defines the primary hue and chroma of the tooth. One chroma more saturated than the desired final shade should be chosen for the cervical and middle third. The most prevalent hue for this dentin layer is A in the VITA Classical shade guide. The opacity should block the mouth's dark background and allow for proper mamelon design and morphology. In this zone, classic microhybrids and larger-particle nanohybrids, predominant in their composition, will generate a high resistance and a Mie-type dispersion, providing a reddish-yellow hue.

Layer 3: This layer fills the depressions in-between, around, and over the mamelons and has little influence on the final strength due to its small quantity. However, it significantly contributes to the occurrence of opalescence. The beauty of incisal layering depends on this layer. A correct opalescence allows a through-and-through transmission of light, like the natural enamel's translucent lamellae, accentuating the Rayleigh type's blue dispersion. For accentuated Rayleigh scattering, the material must have nanometric particles and particles that promote light scattering (between 180 and 700 nm). Its refraction in the organic matrix stands differently than in the inorganic phase. High translucency nanocluster and hybrid resins produce the best results for this area.

Layer 4: This layer must be resistant to abrasion due to the sliding of food during cutting and hygiene techniques through brushing. The area of the cervical and middle third primarily covered by this layer will define the final color of the tooth. In this zone, the sum of the dentin and the thickness of the enamel, with its opaque and translucent lamellae acting as an optical fiber bringing the dentin color, will generate the zone of higher light reflection in the crown. In order to achieve high wear resistance and

TABLE 1 List of commercially available composite resin brands categorized according to filler and colorimetric characteristics.

Layers	Composite classification	Color characteristics	Brands
1	Nanohybrids (medium and large fillers)	Achromatic, translucent, milky	Vita-l-escence PF; Estelite Posterior PCE; Forma Incisal or WE; Miris 2 NR; Inspiro Skin Neutral SN; Renamel Nano Incisal Light; Venus diamond I; Essentia LE; Gradia Direct NT or WT; Filtek Supreme WE
2	Microhybrids or Nanohybrids (large fillers)	O, Opaque, Dentin, D	GrandioSO O colors; Enamel HRI UD colors; Herculite XRV D colors; Vita-l-escence Vita colors; Empress Direct D colors; Inspiro I colors; Renamel Microhybrid Vita colors; Miris S colors.
3	Nanohybrids (micro fillers)	Colors with high translucency and effects	Filtek Supreme GT; Harmonize Incisal Blue; Essentia OM; Vita-l-escence IrB; HRi OBN
4	Nano, micro or nanohybrids (micro fillers)	Body colors or semi-opaque enamels	Renamel microfill Vita colors; Estelite Sigma O colors; Estelite Omega E colors; Harmonize E colors; Herculite Ultra E colors
5	Nano, micro or nanohybrids (micro fillers)	Achromatic (incisal)	Renamel microfill IM; Estelite Sigma CE; Harmonize Clear; Herculite Ultra Incisal; Filtek Supreme CT

TABLE 1 Factors affecting shade selection

• Environment control: Remove lipstick and cover bright clothing.
• Good illumination: Enough amount of light (150–200 lighcandles).
• Quality of light: Illumination around 5500°K.
• Clean teeth: Plaque and biofilm free.
• Dehydration prevention.
• Being brief: Ability of the human eye to perceive color differences 3–5 s.

FIGURE 11 Initial pass of the custom shade guide.

FIGURE 13 Second elimination of tabs with the least close shades.

5 | FABRICATION OF A CUSTOM SHADE GUIDE

The process of fabricating custom shade tabs is relatively simple. A kit (i.e., 3M Shade Maker, 3M China Ltd., Shangai, China) can be bought to make custom shade guides (Figure 6), or an impression of a shade tab or a denture tooth is made in heavy body PVS material (Figure 7). After the PVS material sets, the shade tab is removed and filled with the resin composite material and polymerized

FIGURE 12 First elimination of tabs with the least close shades.

FIGURE 14 Third elimination of tabs with the least close shades.

according to manufacturer's instructions. The new made shade tab is then polished and glued to a metal or plastic tab. An old shade tab holder can also be used for this purpose. These custom shade tabs can then be labeled with the shade and brand of the resin composite used for identification purposes (Figure 8). The process of fabricating layered tabs requires the use of prefabricated molds (i.e., My Shade Guide, Smile Line, Switzerland) to be able to predictably have a consistent and clinically relevant layer of "enamel" over "dentin" materials.

These custom shades tabs should be arranged from perceived light to dark (Figure 8). An example of the Vitapan Classical shade guide arranged by perceived light to dark "value" can be seen in Figure 9. This facilitates the selection process because it places closest color shade tabs based on "Value" in close proximity of each other.

Another popular and effective method is to place small increments of various resin composite shades over the tooth to be restored to select the resin composite shade (Figure 10). This method can be time consuming because the thickness of the increments difficult to control, it does not represent layering, and the risk of dehydration setting in, as well as resulting in increased material cost. In the opinion of not infringe on the supracrestal connective tissue attachment are compatible with periodontal health if they are properly finished and well-polished.[4] One systematic review found teeth restored with DME and indirect restorations to have a better survival rate compared with teeth treated with surgical crown lengthening.[17] All reviews, highlighting the dearth of clinical studies, emphasized the need for further research.

3.4 | Clinical studies

Follow-up periods ranged from 3 months to 21 years.[19,21] Study population sizes ranged from 10 to 120 patients, with a total number of 278 patients and 349 restored teeth included in the six studies combined. In three studies, DME was performed in permanent posterior teeth.[20–22] Reporting of included teeth was incomplete in three articles.[19,23,24] One trial included a randomized allocation of mesial and distal boxes of mesial-occlusal-distal (MOD) cavities to two treatment arms.[22] No article reported blinding of patients, investigators making the assessments, and data interpreters. Two study reports provided information on the time point of the delivery of the indirect restoration, which in one study took place 1 week and in another 12 weeks after DME.[22,23]

3.5 | Clinical performance of teeth with DME and periodontal outcomes

Gingival inflammation levels at sites with DME were found to be similar to untreated sites in a study cohort comprising patients with very good oral hygiene.[19] The cervical margin of DME restorations were located at least 3 mm above the bone level, and patients in this cohort kept weekly recall appointments between the DME procedure and surgical crown lengthening, which was performed in all cases 3 months after DME.[19] In a study with 120 patients, an overall survival rate of teeth with DME of 95.6% was recorded after 10 years of follow-up.[20] No periodontal outcome parameters were reported.[20] A cohort study, providing data on 10 teeth with DME, reported no fractures, secondary caries, or endodontic complications, and DME restorations were rated as "ideal" or "satisfactory" after a mean follow-up of 14 years.[21] DME made either in the mesial or distal box of a MOD cavity revealed more frequent bleeding on probing but no significant changes in plaque and gingival indeces.[22] One study with 15 patients adjusted the treatment protocol depending on the ability to isolate the working field with rubber dam: if the working field could be isolated, DME was performed straightaway.[23] If it could not be isolated, a mucoperiosteal flap was raised.[23] When rubber dam isolation was possible after the flap was elevated, DME was performed without osseous resection.[23] Otherwise, osseous resection was made to allow rubber dam isolation.[23] No significant differences were found between these three treatment groups for probing depth and bleeding on probing. All restorations remained functional and no complications occurred over the 5.7-year follow-up.[23] An assessment of DME restorations made without rubber dam and matrix, sites with DME did not show increased signs of inflammation compared with other sites.[24] Regular interdental brush use was associated with less gingival inflammation, and 70% of the restorations were given high quality ratings after a mean follow-up period of 2.7 years.[24]

FIGURE 2 Preoperative occlusal view of a first molar with deep distal carious lesion. The second molar had failing restorations and recurrent caries.

3.6 | Isolation of the working field

Rubber dam was used to isolate the working field prior to DME in five of the six clinical studies included in this review.[19–23] Cotton rolls, suction, retraction cords, and astringent agents during the DME procedure and rubber dam isolation thereafter were used in one study.[24]

FIGURE 3 After rubber dam isolation, initial excavation with hand instrument

FIGURE 4 Situation after complete caries removal

3.7 | Teeth used in *in vitro/in silico* studies

Molars were selected as tooth specimens in 19 studies.[7,26,27,29–33,33,35–37,39–43,45,46] Nine study reports did not specify whether permanent molars, deciduous molars, or both were used.[27,32–36,39–41] Premolars were selected in four studies,[25,28,44,47] while one study used typodonts.[38] Except for the investigation that used typodonts, none of the included laboratory studies simulated physiological interproximal contacts.

3.8 | Matrix

Most clinical studies used metal matrices for DME.[20,22,23] Operators in one clinical study performed DME without a matrix.[24] Two reports of clinical investigations and 12 reports of *in vitro* studies furnished no information on matrix use.[7,19,21,25,27,29–31,33,39,40,43,46,47] Circumferential metal matrices were used in nine laboratory studies.[26,32,32,35–38,44,45] A laboratory study on typodonts demonstrated the advantage of packing Teflon (PTFE) tape behind a sectional metal matrix placed within a circumferential metal matrix to obtain a tight marginal seal in deep proximal cavities.[38]

3.9 | Adhesive strategies for DME

An etch-and-rinse approach, either with a conventional etch-and-rinse adhesive or a universal adhesive, was employed in two clinical investigations and 12 *in vitro* studies.[7,20,24,25,27,29,33,35,37,38,40,41,43,45] Selective enamel etching, either with a conventional self-etch adhesive or a universal adhesive, was chosen in one clinical investigation and nine

FIGURE 9 Lateral view of prepared molar after removal of the provisional restoration. Air-borne particle abrasion was applied to the resin-based composite (RBC) to prepare the deep margin elevation (DME) surface for bonding of the onlay.

FIGURE 10 Total-etch technique with phosphoric acid

FIGURE 11 Bonding agent application

FIGURE 12 The ceramic onlay was etched with hydrofluoric acid

FIGURE 13 Silane coupling agent application

FIGURE 14 Ceramic onlay inserted with resin-based luting material

3.14 | Load cycling/artificial aging of restored teeth in *in vitro/in silico* studies

In most of the included studies, the restored teeth were subjected to thermomechanical load cycling or mechanical load cycling.[26,27,30–34,39–47] In four studies, the specimens were not exposed to any loading or artificial aging.[29,35–37]

3.15 | Dental healthcare survey data

In a questionnaire-based study, comprising a convenience sample of 535 dental practitioners in Riyadh, Saudi Arabia, 66.9% and 30.4% of the respondents reported to be familiar with DME and to use it in clinical practice, respectively.[48]

FIGURE 10 Labial view of the now 81-years old patient.

FIGURE 11 Frontal view of the RBFDP 26 years after insertion. Note the clinically not relevant loss of hard and soft tissue caused by physiological aging.

FIGURE 12 Occlusal view of the RBFDP after 26 years.

FIGURE 13 Labial view of a 15-year-old female patient with unilaterally congenitally missing maxillary right lateral incisor.

FIGURE 14 The edentulous space showed slight soft tissue excess in vertical direction but a moderate ridge defect in horizontal direction.

FIGURE 15 View of the master cast demonstrating preparation features. The edentulous area of the cast was reshaped to achieve an ovoid support of the pontic.

3 | CLINICAL FOLLOW-UP CASE 2 OVER 26 YEARS

A 15-year-old female patient presented with a congenitally missing maxillary right lateral incisor (Figure 13). The edentulous space showed slight soft tissue excess in vertical direction but a moderate ridge defect in horizontal direction (Figure 14). After minimally invasive preparation of the abutment tooth within the enamel and impression taking (Figure 15), the single-retainer alumina ceramic RBFDP was fabricated with a copy-milling technique and labially veneered with feldspathic ceramic. The edentulous area of the cast was reshaped to achieve a concave rest area for an ovate pontic. Due to the ovoid pontic, the soft tissue became ischemic when the RBFDP was tried on clinically (Figure 16). To avoid hyperpressure of the ovate pontic,[15] the soft tissue was reshaped using an electrotome sling as an electrical cutting instrument to fit the ovate pontic leaving more than 2 mm of soft tissue between the pontic and the supporting alveolar bone (Figure 17). A minimum tissue thickness of 2 mm between the pontic and the alveolar bone

FIGURE 16 Due to the ovoid pontic the soft tissue became ischemic when the RBFDP was tried on.

FIGURE 17 After local anesthesia, the soft tissue was reshaped using an electrotome sling for adaptation to the ovate pontic.

FIGURE 18 Labial view at the day of insertion of the RBFDP

FIGURE 19 Occlusal view at the first recall visit

FIGURE 20 Smiling 15-year-old patient.

FIGURE 21 Smiling 41-year-old patient 26 years later.

respects the biological width by leaving enough space for the periosteum, connective tissue, and epithelium.[16] Then, the restoration was inserted with a phosphate monomer luting resin (Panavia 21 TC, Kuraray, Japan) under rubberdam isolation. The soft tissue wound healed against the ovate pontic (Figure 18). At the following recall visit the tissues had healed and the patient was satisfied (Figures 19 and 20). In October 2022 the now 41-year-old patient was met at a café in Cologne (West Germany) and the restoration was inspected (Figures 21 and 22). The soft tissues around the pontic looked healthy and no clinically relevant loss of soft tissue was detected. The RBFDP has never lost retention and no tooth migration or rotation of the pontic has occurred. However, the patient's natural teeth had become somewhat darker over the years due to natural aging, so that the pontic now appeared considerably lighter than the natural dentition. The patient was advised either to bleach the natural teeth or to replace the veneer of the pontic with a veneer of a better matching color.[17]

4 | TODAY'S STANDARD TREATMENT USING VENEERED ZIRCONIA—FOLLOW UP OVER 18 YEARS

After the availability of densely sintered zirconia ceramics for the fabrication of dental restorations in the early 2000s and the

FIGURE 10 Pressed lithium disilicate monolithic occlusal onlays (Figure 5) after 49 months of clinical service with visible wear

FIGURE 11 CAD/CAM resin composite restorations after adhesive bonding with high surface gloss at baseline recall

FIGURE 12 CAD/CAM resin composite restorations (Figures 11, 14) with marginal discoloration after 64 months of clinical use. The surface appeared dull with visible wear

FIGURE 13 Repairable distobuccal fracture of CAD/CAM resin composite restoration (FDI 46) after 44 months of clinical service

FIGURE 14 CAD/CAM resin composite restorations after adhesive bonding with high surface gloss at baseline recall

FIGURE 15 CAD/CAM resin composite restorations (Figure 14) with discoloration and crack of first premolar (FDI 24) and perforation on second molar (FDI 26) after 58 months of clinical service. Surface appeared dull with visible wear

were analyzed using SPSS 25 (SPSS) with a significance level of $p < 0.025$ to adjust for the variability in patient selection for the two different material groups.

3 | RESULTS

3.1 | General information

The mean age of the 21 patients was 44.1 ± 9.3 years and the mean observation period was 86.2 ± 13.5 months (7.7 ± 1.1 years). All patients were non-smokers and were seen at the clinic due to esthetic concerns, hypersensitivity, functional and masticatory problems, as well as in very rare cases pain.

All patients were treated with tooth-colored single-tooth restorations ($N = 436$), whereas 274 lithium disilicate ceramic restorations were made, of which 176 monolithic lithium disilicate restorations were placed in the load-bearing posterior regions (IPS e.max Press); 144 monolithic occlusal onlays, 32 crowns, and 98 lithium disilicate

FIGURE 16 CAD/CAM resin composite restorations (Figure 14) with discoloration and crack of first premolar (FDI 24) prior to change of prosthetic rehabilitation from CAD/CAM resin composite to monolithic lithium disilicate restorations after separating of CAD/CAM resin composite crown after 72 months of clinical service. Discoloration resulted of an adhesive failure between CAD/CAM resin composite and luting composite

FIGURE 17 CAD/CAM resin composite restorations (Figure 14) with discoloration and crack of first premolar (FDI 24) prior to change of prosthetic rehabilitation from resin CAD/CAM composite to monolithic lithium disilicate restorations after removal of CAD/CAM resin composite crown after 72 months of clinical service. Luting composite remained on abutment tooth as a sign of adhesive failure on the inner surface of the restoration

frameworks with manual veneering in the esthetic anterior regions (IPS e.max Press with IPS e.max Ceram). In addition, 162 monolithic CAD/CAM resin composite restorations were fabricated, of which 140 were in the posterior region (77 occlusal onlays, 59 partial crowns, four full crowns), and 22 in the anterior region (20 veneers and two crowns).

3.2 | Lithium disilicate restorations

Within the group of lithium disilicate ceramic restorations, five female and seven male patients with a mean age of 41.2 ± 8.2 years (female, 48.2 ± 5.8; male, 41.3 ± 8.6) were treated with a mean observation time of 95.0 ± 33.3 months (8.5 ± 2.7 years).

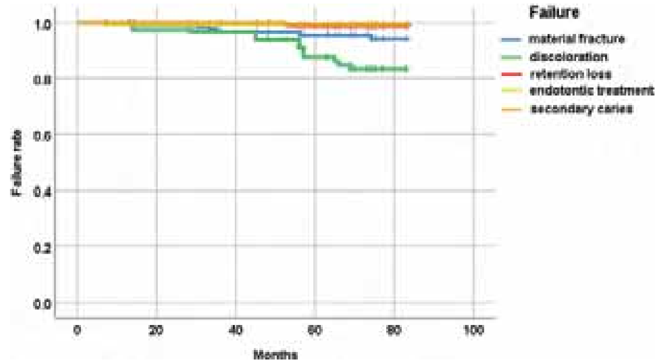

FIGURE 18 Kaplan–Meier rate for failure rates of CAD/CAM resin composite restorations

The total failure rate of lithium disilicate ceramic restorations was 5.5% with a total annual failure rate (AFR) of 0.5%. All technical failures were rated Bravo (Table 2 and Figure 6–9) with an AFR of 2.9% and discoloration with an AFR of 2.2%. For the lithium disilicate restorations, no biological complications were found. Visible occlusal wear (rated Bravo) occurred in 67.5% of the lithium disilicate restorations (Figure 10).

3.3 | CAD/CAM resin composite restorations

Within the group of CAD/CAM resin composite restorations, seven female and two male patients with a mean age of 44.0 ± 10.8 years (female, 44.3 ± 9.1; male, 43.0 ± 15.3) were treated with a mean observation time of 74.0 ± 6.3 months (6.7 ± 0.5 years). Details for the patients included are summarized in Table 2.

The total failure rate of CAD/CAM resin composite restorations was 25.3% (Figure 6) with a total AFR of 3.8%. CAD/CAM resin composite restorations exhibited more material fractures ($p = 0.020$, AFR: 6.2%) and higher discoloration rates ($p < 0.001$, AFR: 14.2%) analyzed with the log-rank test.

Thirty-nine technical failures and two biological failures occurred (one secondary caries after 52 months and one necessary endodontic treatment after 7 months), all rated Bravo (for details see Table 2). Occlusal wear (rated Bravo) was documented in 91.1% of the CAD/CAM resin composite restorations after 6 and 7 years in situ (Figures 11–18).

Neither restorative material presented any difference in survival, with no loss of restoration to follow-up.

Detailed survival and failure rates for both restoration types are listed in Table 3. Survival and failure rates as primary outcomes are listed in Table 4.

4 | DISCUSSION

Full-mouth rehabilitations of patients with moderate to severe loss of dental hard tissue with progressive VDO reduction usually represent a

FIGURE 3 (A) Preoperative periapical radiograph of failing right central incisor (#8). (B) Sagittal CBCT view of failing right central incisor with class 1 sagittal root position

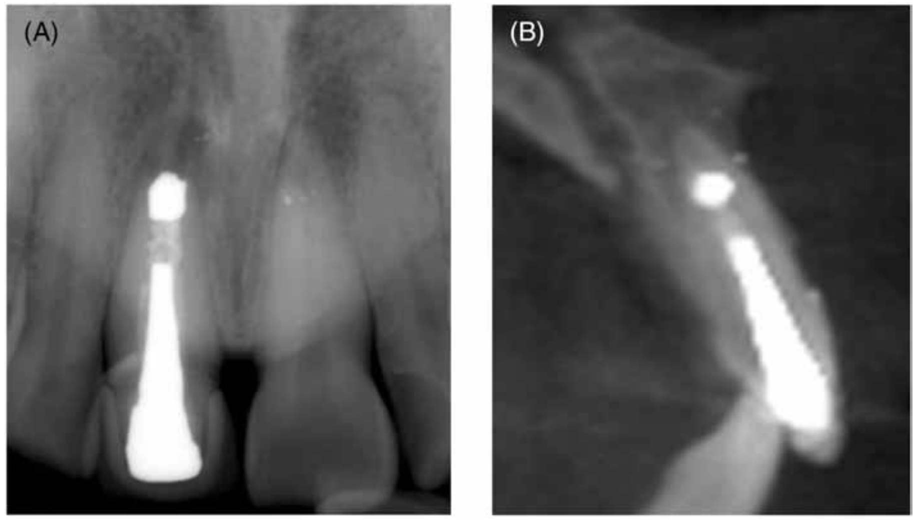

FIGURE 4 Bone sounding measurement of 3 mm at mid-facial aspect of right central incisor showing intact facial bone

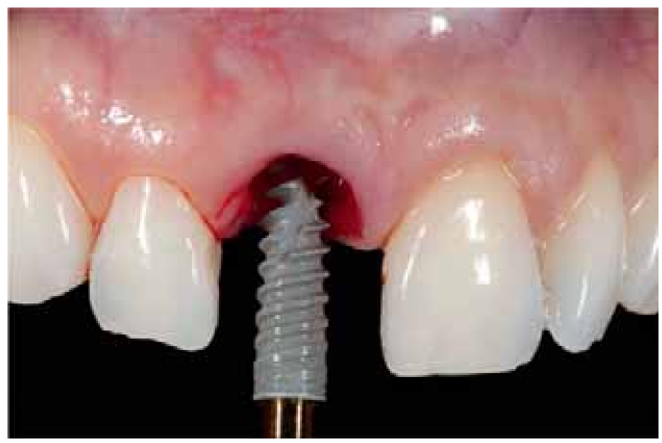

FIGURE 5 A 3.5 × 13 mm implant was placed immediately into the socket

FIGURE 6 The implant was placed palatal to the socket leaving a minimal facial gap of 1.5 and 1.0 mm gap palatally. A Scarf-CTG (S-CTG) was harvested from the lateral palate to be placed at the soft tissue zone

FIGURE 7 A 50/50 mixture ratio of small particle xenograft and allograft was placed within the gap between implant and the extraction socket

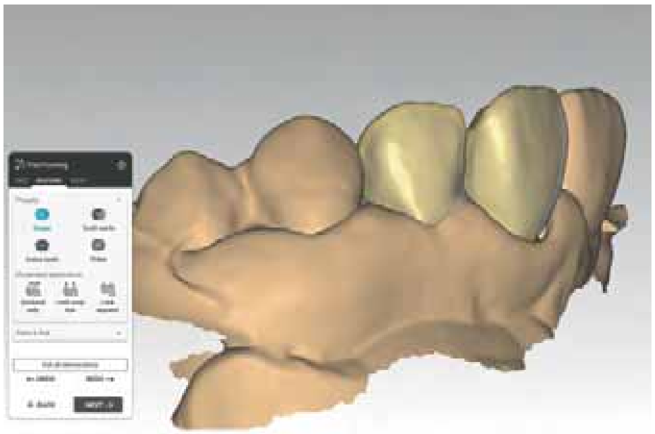

FIGURE 13 Digital design for zirconia crowns with cut back for porcelain veneer microlayer.

FIGURE 14 Porcelain layering of zirconia crown copings.

FIGURE 15 For bisque bake try in, the crown was attached to the titanium base with cyanoacrylate for fixation during try in and easy removal afterwards.

FIGURE 16 Intraoral bisque bake try in. Control of value is a challenge without opaque resin cement.

FIGURE 17 Shade communication with the dental laboratory with photos.

FIGURE 18 A customized master cast was fabricated, simulating the shade of adjacent teeth and underlying structures to optimize shade match and adapt chroma and value of the restorations.

FIGURE 3 Baseline—clinical and CBCT outcomes prior orthodontic appliance removal (A–C), baseline—at the day of surgery (D), flap elevation (E), grafting procedures (allogeneic bone graft + ADM (F,G), flap suture (H), 12 months follow-up—clinical and CBCT outcomes (I–K), baseline versus 12 months follow-up—occlusal view (L,M)

FIGURE 5 Surgical procedure with the double guide. (A) Evaluating the double guide fit on teeth and soft tissue. (B) Internal bevel incision performed with scalpel blade 15C perpendicular to the inner edge of the window of the guide, outlying the new gingival margin. (C) Soft tissue removal with a periodontal curette. (D, E) Upper arch after gingivectomy and confirmation through the guide. (F) Intrasulcular incision with an ophthalmologic scalpel blade. (G) Full-thickness mucoperiosteal flap elevated, note that the bone crest is mostly at the level of the CEJ. (H) Repositioning of the guide to perform the osteotomy. (I) Marking the osteotomy limit with spherical diamond bur according to the outer edge of the window of the guide. (J) Vertical bone level established. (K, L) osteotomy and osteoplasty finished and flap sutured. (M) Repositioning the guide and the comparison of planned and achieved gingival margin (quality control)

FIGURE 1 Occlusal view highlighting the periodontal and peri-implant soft tissue of the maxillary central incisors.

FIGURE 2 On the natural tooth a #000 retraction cord has been placed into the sulcus to horizontally and vertically displace the marginal gingiva, whether on the implant site an open tray impression coping has been customized extra-orally to support the peri-implant mucosa.

FIGURE 3 Occlusal view of the final prostheses. Note the profiles of the restorations that contour the soft tissue.

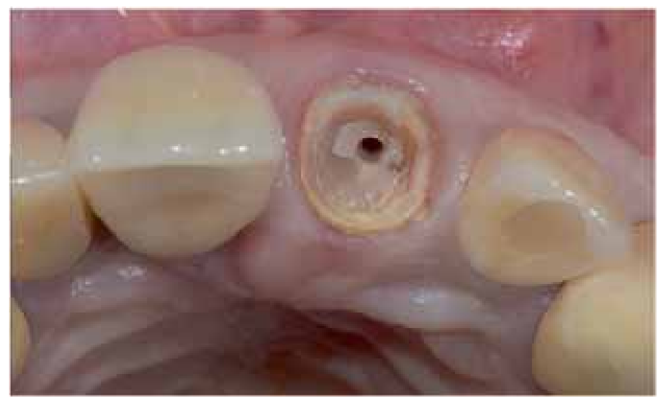

FIGURE 4 Maxillary left central incisor broken at gum line and judged non-restorable due to a palatal fracture.

FIGURE 5 A partial extraction therapy approach was performed. The root was sectioned mesio-distally and a C-shape fragment of dentin was left facing the buccal site of the socket to maintain the supracrestal attached tissue. The coronal margin of the fragment was reduced until reaching the level of the facial bone crest.

FIGURE 6 A tall and narrow healing abutment was placed and the marginal gap was filled with small-particle bone graft. The dual-zone bone grafting (i.e., placement of the bone graft in the gap between the implant and the labial bone plate, as well as in the zone above the implant-abutment junction) provides support and volume to the hard and soft tissues

A detailed treatment planning, precise 3D position of the implant and adequate soft tissue volume facilitate the achievement of a final natural esthetics.[11] A screw retained temporary prosthesis is commonly used to support and condition the soft tissues by generating an emergence profile that replicates and mimics the tissue architecture of the adjacent dentition.[12]

Significant amount of time is often required to optimize the morphology of the temporary restoration and waiting for tissue maturation, managing the critical and subcritical contour by adding or

FIGURE 20 Detail of tissue stability 3 years after cementation (master ceramist Luca Dondi)

4 | CONCLUSIONS

The copy–paste full digital workflow simplifies the fabrication of the definitive prosthesis, allowing a precise replica of the emergence profile and angle of the temporary prosthesis. The dental technician can simply copy the morphology of the temporary prosthesis and the subgingival contour that has been established by the dentist and he will be able to fabricate a definitive prosthesis in few steps.

PATIENT CONSENT

All treated patients signed an informed consent to their treatments.

DISCLOSURE

The authors declare that they do not have any financial interest in the companies whose materials are included in this article.

DATA AVAILABILITY STATEMENT

The data sets used and analyzed during the current study are available from the corresponding author on reasonable request.

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FIGURE 35 Arches after orthodontic treatment

FIGURE 36 Connective tissue augmentation of the pontic site and facial soft tissue of the central incisor

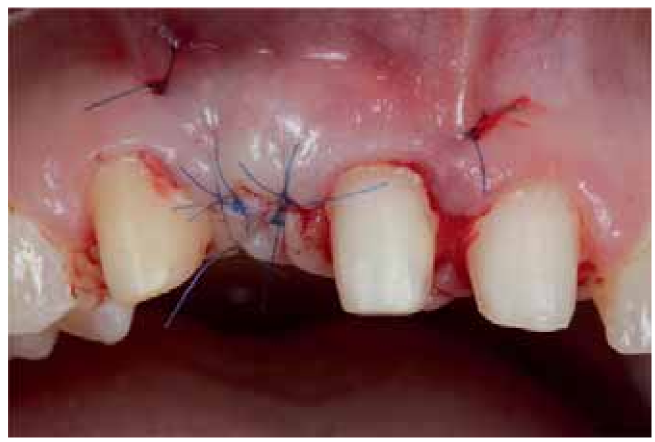

FIGURE 37 Site after perio-plastic surgery

FIGURE 38 Healing of the site 1 week post-OP with transitional chair-side temporary restoration.

FIGURE 39 Long-term temporary

compare the accomplished new tooth position with the defined treatment goal (Figure 23). Meanwhile during the final phase of the orthodontic treatment, the failing central was extracted and the site was left for healing for 6 weeks. After healing, an implant (Bone Level Tapered, Straumann, Switzerland) was placed in a straight-forward procedure with a transgingival healing approach.[19] After successful healing of the implant (Figure 24) the restorative phase for nonprep veneers and an implant crown started (Figures 25–27).

After the patient approved the esthetic result, the restorations were adhesively cemented and the occlusion was adjusted (Figures 28–30). In

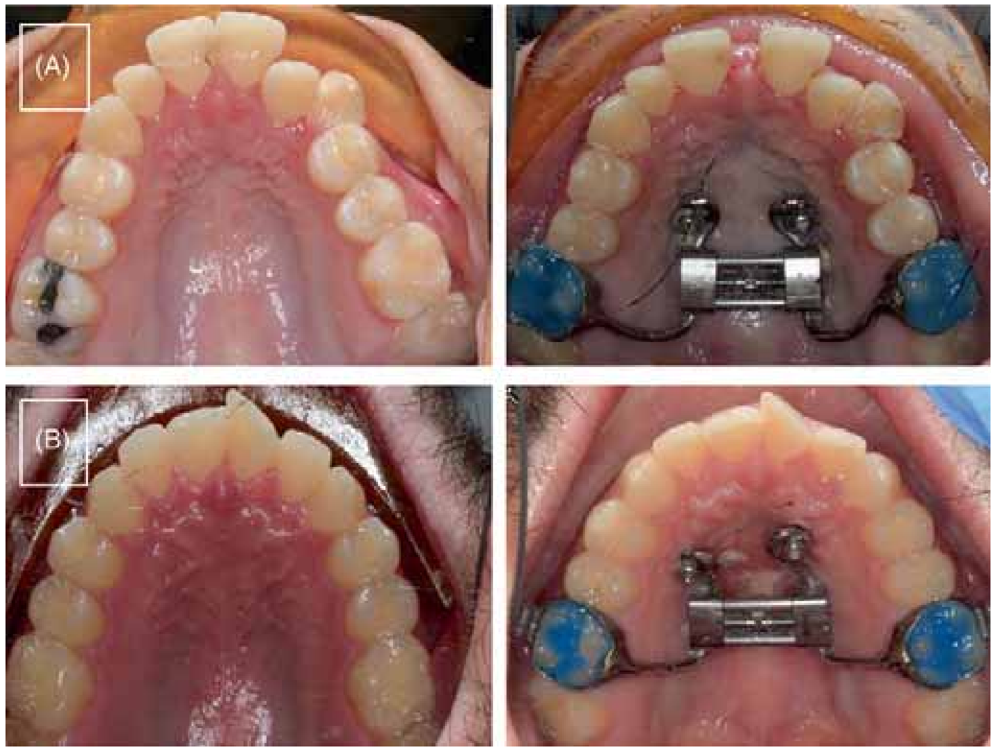

FIGURE 6 (A) Successful maxillary skeletal application in a young adult with a hybrid MARPE. (B) Another young adult in the same age not responding to MARPE

could present challenges for the patients and the practitioners in the practice setting. Therefore, it is a worthwhile topic to investigate and make clinically relevant innovations.

4 | A NEW CONCEPT FOR BONE-BORNE MARPE

Traditionally, tooth-borne palatal expanders are designed to be supported by four anchor teeth. As indicated before, MARPE appliances may include two (Hybrid) or four miniscrews to replace the anchor teeth. MARPE designs supported with four-miniscrews may also have additional tooth-borne support, such as a palatal bar connecting the maxillary right and left first molars.

Adding a transpalatal bar inevitably transforms the appliance design into a combination of a tooth- and bone-borne expander. In a study where pure bone-borne MARPE (supported with only four miniscrews) was compared to the tooth- and bone-borne combination MARPE (four-miniscrews and a palatal bar between the first molars) 100% success was achieved in midpalatal suture separation. However, the bone-borne appliance caused a significantly more significant skeletal width increase, fewer dental side effects, and less buccal bone reduction than the combination MSE appliance.[30]

Depending on where and how the miniscrews are inserted, it is possible to use longer miniscrews and obtain bicortical anchorage, including the palate and the nasal floor. While it may be argued that obtaining bicortical anchorage is not associated with success,[24] bicortical anchorage could reduce the lateral drift of the miniscrews when subjected to heavy forces.

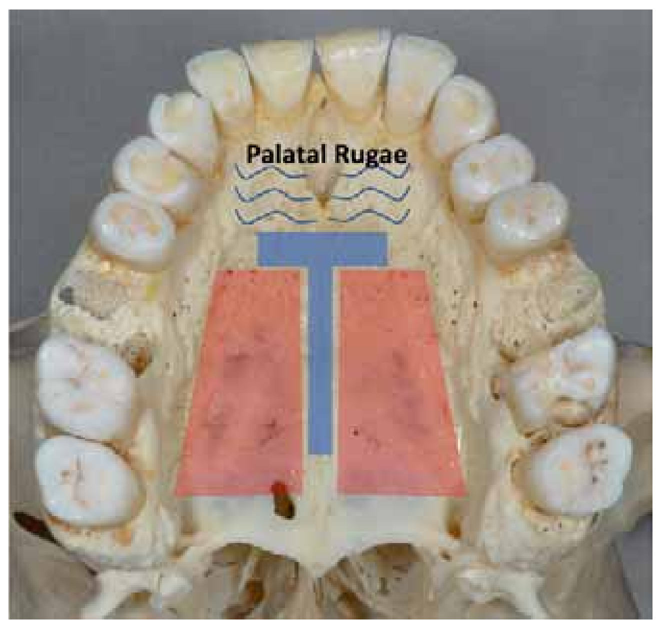

FIGURE 7 The “T zone”: redrawn from Wilmes et al.[32]

In general, the anterior palate offers an outstanding amount and quality of bone, particularly an area distal to the third rugae extending medially toward the bicuspids and over the midpalatal suture posteriorly. Clinicians refer to this area (Figure 7) as the “T-zone.”[31,32] Extensive research has been done in the anterior palate region and confirmed the presence of adequate quality bone for miniscrew placement.[33–38] When viewed from the profile, that is, looking at a cephalometric radiograph, maxillary bone tapers from anterior to posteriorly. Therefore,