"When our profession changes someone's life in such a profound way, everyone who contributed to the case feels the impact."

An Impactful Journey

By Michael R. Sesemann, DDS, FAACD

"My dental journey actually started before I had teeth" were the intriguing words of the patient featured on the cover of this issue. She went on to explain that she had been given tetracycline as an infant to treat an illness and, as a result, when her adult teeth erupted they exhibited deep gray and purple stains. All the dentists she had consulted over the years had told her that her teeth were the darkest or second darkest they had ever seen. Because of this she smiled with her mouth closed and sometimes she avoided smiling altogether.

Veneers had been applied to mask the discoloration when she was a teenager. Although she was pleased with their esthetics they chipped and broke frequently. The next step in her dental journey occurred while she was a college student in the mid-1980s, when crowns were placed on the eight upper teeth in her smile zone. Looking back, she said those original crowns were extremely opaque, very bulky, and thick, "almost like horse teeth."

In 2017, motivated by a root canal and her daughter's upcoming wedding, she sought a dentist in her hometown of Omaha, Nebraska, who could provide her with the beautiful, natural-looking smile she had always desired. Research led her to the author's practice... and to a new smile created with the help of renowned ceramist Lee Culp.

"When I first got my new teeth, I wanted to cry. They gave me the confidence that I've always been looking for. They're me! I love the shape, the color, the size—everything is authentic and natural," she exclaimed.

This patient had waited her entire life to have a smile that expressed her personality. The evolution of dental technology and materials united with clinical acumen and technical skill to finally fulfill her wishes as well as the restorative team's goals of strength, durability, lifelike texture, and natural color. When our profession changes someone's life in such a profound way, everyone who contributed to the case feels the impact.

Dr. Sesemann thanks Ms. Barbara Ruser for her help in developing this article; and the patient for her courage and positive attitude.

Turn to page 28 to read Dr. Sesemann's clinical cover article, co-authored by Lee Culp, CDT, and Lida Swann, DDS, MS.

Cover image: Photographer: Bryan Jamieson (Amherst, NY). Camera: EOS 5D Mark III (Canon; Melville, NY) with a Canon EF 70-200mm lens and four constant light sources.

Restoration of Extremely Dark Tetracycline-Stained Teeth with Monolithic Gradient Zirconia

Michael R. Sesemann, DDS, FAACD
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Abstract
The dentist-laboratory technician restorative team has been challenged over the last 50 years to find a suitable restorative material to treat the extensive tooth staining, born out of the late 1960s and early 1970s, from the ingestion of tetracycline. For milder cases, combinations of bleaching and/or a variety of direct and indirect materials could be effective. However, truly dark teeth necessitated finding a balance between blocking out the darkened tooth structure and the ability to provide lifelike dental restorations with suitable optical metamerisms. This article discusses the properties of dental zirconia and its performance in fixed dental prostheses. A case study illustrating how monolithic, gradient zirconia can provide beautiful, lifelike restorations for even the darkest tetracycline-stained teeth is provided.

Key Words: tetracycline staining, zirconia, monolithic lithium disilicate, veneers, crowns

Introduction
Clinicians and laboratory technicians are dedicated to fixing patients' functional and esthetic problems, the resolution of which can have a profound effect on a patient's quality of life. One of the common esthetic problems the restorative team has struggled with during the past 50 years is how to restore the effects of tetracycline staining of the adult dentition, especially cases that are extremely dark. The challenge lies in the conflicting objectives of adequately blocking out the unwanted darkness and color while providing optical characteristics that mimic natural teeth.

A recent evolution in the composition and technical handling of zirconium dioxide (ZrO_2), also known as zirconia, makes it possible to optimally restore even the darkest tetracycline cases.[1] Zirconia is a white crystalline oxide of the metal element zirconium. Its most naturally occurring form is the rare mineral baddeleyite, although zirconium metal used for dentistry is obtained from the zirconium-containing mineral ore called zircon. After being processed and purified these powders can be further processed to produce somewhat porous bodies that can be CAD/CAM-milled with great precision. Once densely sintered, a polycrystalline ceramic material is produced which, unlike most other dental ceramics, contains no glass phase.

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Tetracycline Staining

Clinical evidence of tetracycline-associated tooth discoloration began to emerge in the mid 1960s.[2,3] It was soon established that tetracycline chelated calcium orthophosphate to form a complex that was irreversibly incorporated into teeth during the calcification stage of tooth development. This resulted in permanent discoloration of the affected dentition. Unfortunately, these findings were significantly delayed because of the significant amount of time that passed between pregnant mothers' or young children's ingestion of the drug until the affected teeth erupted. The clinical presentation of the condition was found to be type-, dose-, and timing-dependent.[4]

Tooth discoloration is the main adverse effect associated with tetracycline taken during pregnancy, especially for exposure in the second and third trimesters during fetal tooth calcification. The drug exposure time-point during gestation defines which teeth will be stained. However, post-natal (from three months to eight years of age) exposure to tetracycline results in lifelong enamel discoloration of the primary and permanent dentition.

Zirconia

Biomaterials in dentistry must address several requirements, which include biocompatibility and strength related to intended purpose and esthetics. The history of dental prostheses reflects a progression from function to esthetics, with gold restorations largely being replaced by porcelain-fused-to-metal (PFM) restorations during the period from the 1970s to the 1990s. The introduction of various all-ceramic restorations beginning in the 1980s initiated a continuous transition from metal-based ceramics to different multilayered and monolithic all-ceramic restorations.

The central issue for all-ceramic restorations has been the balancing of esthetics (color and translucency) with strength or function. Different materials have been utilized and their esthetic value traditionally has been correlated inversely to strength. The basis for this clinical paradox is the use of glass phase ceramics to impart translucency to dental ceramics and the use of relatively opaque crystalline ceramics to achieve strength.

Despite the early esthetic limitations of zirconia-based restorations, it has seen remarkable penetration into the dental laboratory and clinical practice. The reasons for this replacement of metal and metal-ceramic restorations is attributable to several factors, including the relative cost of gold alloys, the integration of zirconia materials into the CAD/CAM workflow, and the esthetic value of "white" dental materials. This migration of clinical preferences from metal ceramics to all-ceramic materials suggests the satisfactory performance of the all-ceramic material.

Literature Review

The past 13 years of clinical research has provided some insight regarding the performance of zirconia prostheses. A systematic review by Raigrodski and colleagues looked at the survival and complications of zirconia fixed dental prostheses (FDPs). They reported survival rates ranging from 73.9% to 100% in 12 studies. Five of these studies reported 100% survival rates during the observation period. One study reported 73.9% survival of frameworks and the remaining six studies found survival rates ranging between 88.2% and 96.6%. The common complication reported was chipping and it was suggested that with the development of new layering porcelains, better clinical properties would be expected.[5]

A systematic review by Schley and colleagues[6] on the performance of zirconia-based FDPs evaluated not only the survival but also the complication rates for this type of prosthesis up to five years. The study followed 310 prostheses. The estimated five-year survival rate for all FDPs was 94.29%. The five-year complication-free rate for technical complications was 76.41%, with chipping being the most reported complication.[6] Very rarely do we seem to see fractures within the zirconia framework itself. For example, a systematic review by Sailer and colleagues[7] indicated that compared to chipping rates of 13.6%, framework fractures occurred at a rate of only 6.5%. Fractures were reported most commonly in connectors of multi-unit posterior restorations and/or second molar abutments.

Larsson's systematic review in 2014[8] suggested that the success rate of tooth-supported and implant-supported zirconia-based crowns is similar, and comparable to that of conventional PFM crowns. A laboratory study utilized indentation to induce chipping of monolithic zirconia and lithium disilicate materials. The results confirm that ceramic veneered-zirconia displayed high chipping and that monolithic lithium disilicate resisted this chipping; however, monolithic zirconia was most resistant to this induced chipping behavior.[9]

Characteristics

As revealed in the aforementioned reviews, one of the early significant observations made regarding the clinical performance of zirconia-based all-ceramic restorations was chipping of the veneering porcelain from the zirconia frameworks. While many different investigators have suggested fundamental reasons for this phenomenon,[9] the clinical response to chipping is a concern for layered zirconia restorations.

When used as a framework, zirconia has an inherent basic esthetic value due to the fact that it is white and can be alternatively colored to mimic surrounding dentin. Further, it can be provided with high opacity to cover discolored teeth and implant components.[10] This can be advantageous to the technician who is trying to conceal a dark underlying tooth structure, a metal post, or the remainder of amalgam restorations left after initial preparation.

Zirconia framework-based restorations, when veneered with an appropriate ceramic layering system, can result in exceptional esthetics and achieve an imperceptible match to the surrounding dentition (**Figures 1 through 3** show images of a 2006 case in which the prosthesis is still in service today). The talented technician may develop appropriate color and optical properties of the restoration within the veneering ceramics. However, the past decade of investigation has revealed that chipping within the veneering ceramic or at the framework/veneer interface frustrates higher clinical success and survival of these restorations. Veneer chipping, not framework fracture, appears to be the weak link in zirconia-based restorations.

Biocompatibility

Research on zirconia as a biomaterial began in the late 1960s with Helmer and Driskell.[11] Nearly 20 years later, Christel suggested the use of zirconia as an alternative to other materials used at the time, to manufacture the ball heads for total hip replacements.[12] Zirconia is still used today in this application and for other medical prosthetics. Studies show that zirconia was found to be superior to other ceramic biomaterials in use circa 1990 because it possessed higher strength and hardness.[7,13]

The interaction of zirconia with oral soft tissues may be central to the performance of tooth- and implant-supported restorations.[14] The formation of biofilm on dental prostheses, either natural tooth or implant-supported, is material-related. A 2014 investigation measured the colonization of dental implant abutments.[15] DNA checkerboard analysis revealed that, compared to zirconia abutment materials, higher total bacterial counts were greater on cast or machined titanium discs after 24 hours. This confirms the work of Bremer and colleagues, who showed that biofilm was lowest and thinnest on zirconia compared to lithium disilicate restorations.[16] The clinical impression that low biofilm formation and limited inflammation at zirconia restorations is supported by such in vitro and in vivo studies. Bacterial adhesion has proven to be slightly better that titanium. Scarano and colleagues reported a degree of coverage by bacteria of 12.1% for zirconia as compared to 19.3% on titanium.[17] Rimondini and colleagues confirmed these results with an in vivo study where y-TZP accumulated fewer bacteria than titanium in terms of total numbers of bacteria and presence of potential pathogens such as rods.[18]

Based upon the above-mentioned findings, it may be concluded that zirconia materials offer advantages of biocompatibility for use as endosseous and oral biomaterials due to their remarkable strength and durability, as well as their surface properties.

Strength

The introduction of zirconia-based ceramics as a restorative dental material has generated much interest in the dental profession. The mechanical properties of

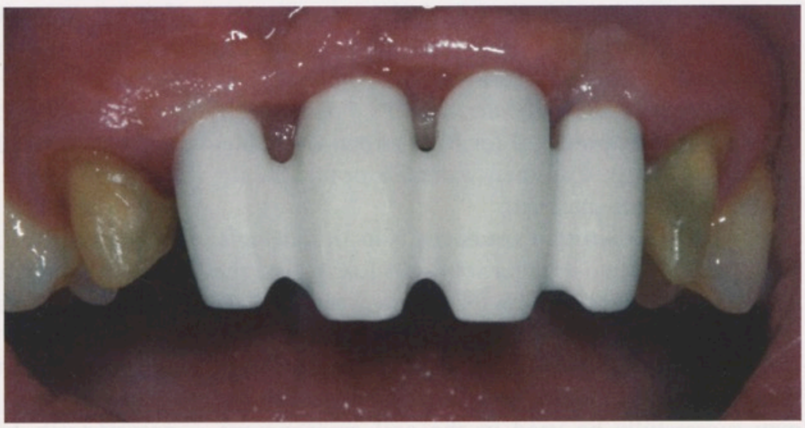


Figure 1: Implant-supported zirconia framework used by the restorative team for a patient in 2006 to restore missing teeth #7 to #10 and accompanying osseous defect.

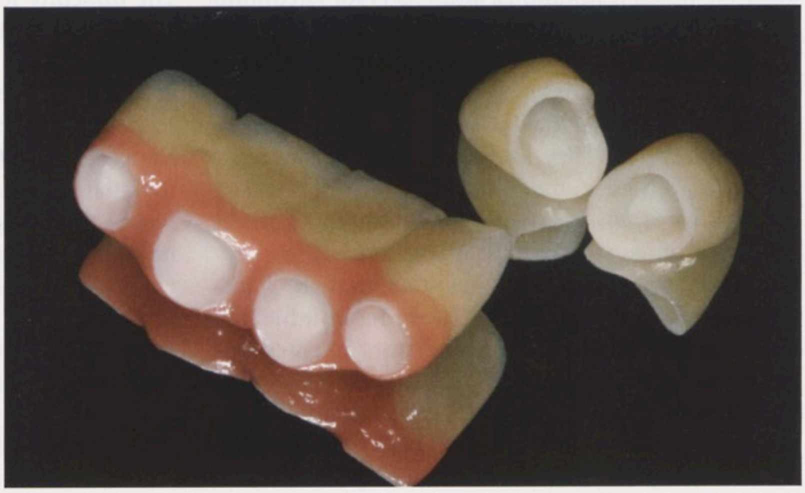


Figure 2: Completed implant-supported zirconia framework bridge with pressed leucite-reinforced ceramic (both pink and white) for final tooth and gingival form with ceramic layering to characterize the final appearance.

Figure 3: Prosthesis seated in 2006 still in service in 2018. Cuspid full-coverage restorations with pressed leucite-reinforced ceramic.

zirconia are the highest ever reported for any ceramic used in prosthetic dentistry and its strength has allowed the incorporation of high-strength all-ceramics into its use for posterior FDPs.[19] Its strength, coupled with its potential for high esthetics, enables zirconia to be an extremely valuable option in the prosthetic armamentarium.

The basis for zirconia's strength is its unique crystalline structure and its behavior under loads. Over the last decade or so, many high-strength ceramics have been developed for the construction of metal-free restorations.[20] Several studies have evaluated different all-ceramic systems and suggested where these systems may successfully be used in the oral environment. Lüthy and colleagues measured average load-bearing capacities for several ceramic systems and found 518 N for alumina-based restorations, 282 N for lithium disilicate-based restorations, and 755 N for zirconium restorations.[21] Raigrodski and colleagues also analyzed several different all-ceramic systems, concluding that those in their study were to be used only in the anterior, for single-crown restorations and possibly three-unit FPDs.[20] They also concluded that because of zirconia's higher strength it offers a wider area of restorative options in the oral cavity, including posterior single units, and multi-unit restorations.[20]

Another option is fracture-resistant, partially translucent monolithic ceramics. These monolithic all-ceramic restorations are becoming more accepted due to their higher strength, by avoiding weak veneer-core interfaces. Materials such as IPS e.max lithium disilicate and Wieland Zenostar zirconia (Ivoclar Vivadent; Amherst, NY), and Lava Plus zirconia (3M ESPE; St. Paul, MN) have acceptable esthetics and can eliminate the need for veneering ceramics altogether.

Wear

During the early 2000s it was believed that the use of zirconia would create high wear in the opposing dentition. That perception has since been challenged[22] and multiple studies have shown that zirconia can be a material gentle to opposing dentition,[23,24] in comparison to glass ceramics that are layered on PFM restorations. This low-wear property can be attributed to zirconia's microstructure and its small grain size, which allows for a "polished mirror" surface to be created that is kind to opposing enamel surfaces.[23,24]

An in vitro study by Yung and colleagues[25] evaluated the wear of enamel opposing zirconia surface. They found that zirconia surfaces appear to be less abrasive to enamel than feldspathic porcelains. They also found that polished zirconia without glazing is less abrasive than zirconia-glazed surfaces.[25] Janavula and colleagues also evaluated the wear of enamel by full-contour polished and glazed zirconia. A wear simulator producing a 4-mm slide at 20 N rate was applied and samples evaluated using a non-contact 3D profilometer. Although the wear of glazed zirconia was more than polished zirconia, it was still less than that of commonly used porcelains for PFM restorations.[26]

These results were investigated further in a six-month clinical study that evaluated the wear on opposing dentition for monolithic full-contour zirconia prostheses.[27] Twenty monolithic crowns were placed in patients and mean vertical loss for specimens, antagonists, and contralateral was recorded. Both mean and maximum enamel wear were significantly different between the antagonists of the zirconia crowns and the contralateral antagonists. Under clinical conditions, monolithic zirconia crowns seem to be associated with more wear of opposed enamel than natural teeth, but the amount of wear is comparable to if not less than that of other ceramic systems.

Esthetics

The difficulty in achieving predictable excellent esthetics with PFM restorations and the desire for metal-free solutions has led to the increased use of zirconia, whose unique optical properties require new and different understanding of how the materials are managed.[28] Translucency and color are important and often inseparable variables for dental restorations; and translucency may be an innate optical property of the zirconia material related to its crystalline structure. Over the past 16 years there has been a remarkable evolution in the esthetics of full-contour zirconia, as raw material manufacturers and ceramic companies work together to improve translucency and optical properties within this unique biomaterial.

At the beginning of dentistry's use of zirconia, with systems and materials from Cerec, Dentsply Cercon, Vita, Ivoclar Vivadent, and others, there were only two choices: white or opaque. Then 3M ESPE introduced dyeing liquids that allowed for the internal coloring of zirconia frames. However, ceramics were still being layered to achieve final tooth form and esthetics. It was not until full-contour solid zirconia restorations became popular that serious research into the material's esthetics became the focus of zirconia development. Since that time there has been significant research and development on this material's specifications and esthetics.

In the last few years zirconia technology has offered the technician both higher translucency and pre-shaded discs in all A-D shades. New multilayered zirconia milling discs offer a transition from dentin to enamel shades, along with proper translucency differences in those areas. These zirconia discs offer the dental technician, dentist, and patient a universal restorative option for both anterior and posterior applications that rivals the esthetics of traditional hand/brush-layered ceramics.

New Material

Zirconium oxide block IPS e.max ZirCAD medium translucency (MT) Multi offers excellent esthetics and high strength at over 850 MPa due to a blending of shade and translucency, but also a transition from less translucent at the cervical to more translucent at the incisal. Intraoral observations show that very esthetic restorations can be made with this material with a cervical/circular wall thickness of 1 mm and an opacity of approximately 68%. The MT raw material is employed in the cervical part; in the incisal part, where the wall thickness naturally increases to 1.5 to 2 mm, a higher translucency is achieved with the blending of a 5Y-TZP zirconia. Therefore, e.max ZirCAD MT Multi has a gradient of the composition from 4Y-TZP up to 5Y-TZP, which leads to a natural appearance in the oral environment. The incisal part in particular is characterized by natural light transmission so that this material can be used for anterior restorations without any layering and/or applying veneering ceramics.

Case Study

Patient Complaint and Findings

A 48-year-old female presented to the treating clinician's practice seeking options for the restoration of her front teeth. She wished to replace 30-year-old PFM restorations in the maxillary arch and fix very dark tetracycline-stained teeth in the mandibular arch **(Figs 4 & 5)**. A biomechanical, tooth-by-tooth analysis of the patient's existing restorations indicated that new restorations were necessary **(Figs 6 & 7)**. The results of the biomechanical analysis, in conjunction with an occlusal diagnosis of dysfunction, resulted in a treatment plan for a full-mouth rehabilitation to satisfy the patient's esthetic objectives while meeting the dentist's functional parameters. Clinical examination also determined that the patient had reticular lichen planus lesions of the attached gingiva and the buccal mucosa.

Treatment

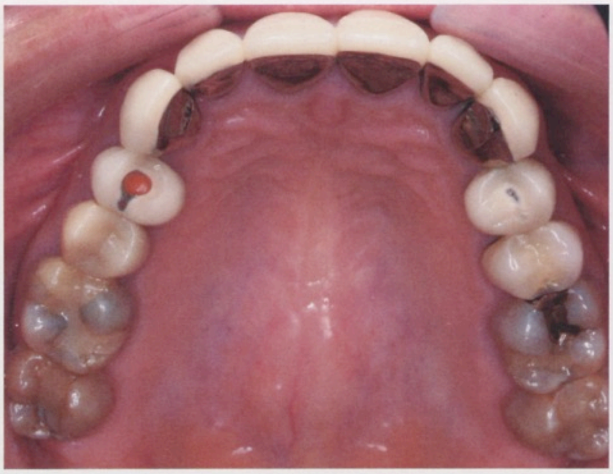
Endodontic procedures were completed for numerous teeth and an allograft (AlloDerm, BioHorizons; Birmingham, AL) was performed for #8 to treat recession and optimize the maxillary anterior gingival architecture for smile design purposes (the patient revealed the full length of #8 even with a guarded smile). The gingival grafting procedure was necessary to make the central incisors mirror images for an optimal esthetic result.

Monolithic lithium disilicate (e.max) posterior restorations were completed in the laboratory while the gingival graft healed. The clinician's preference is to utilize monolithic lithium disilicate for posterior restorations because it allows the capability to "see through" the restorations on radiographs at recare visits. While the posterior restorations were being fabricated, the restorative team decided to utilize a new gradient zirconia, e.max ZirCAD MT Multi, for the anterior restorations. The anterior teeth were prepared for these full-coverage zirconia restorations, images were taken to communicate the patient's stump color **(Figs 8 & 9)**, and provisionals were made from the diagnostic wax-up. After the provisionals were adjusted for functional occlusion and

Figure 4: Patient's natural smile, 1:2 magnification.

Figure 5: Retracted 1:2 view of the patient's PFM crowns in the maxillary arch and the deep tetracycline-stained teeth in the mandibular arch.

> "...post-natal (from three months to eight years of age) exposure to tetracycline results in lifelong enamel discoloration of the primary and permanent dentition."



Figures 6 & 7: Maxillary and mandibular occlusal views showing multiple restorations at the end of their useful service.

Figure 8: Shade guides next to the patient's lower anterior teeth illustrating the enormous change from the existing to the future shades.

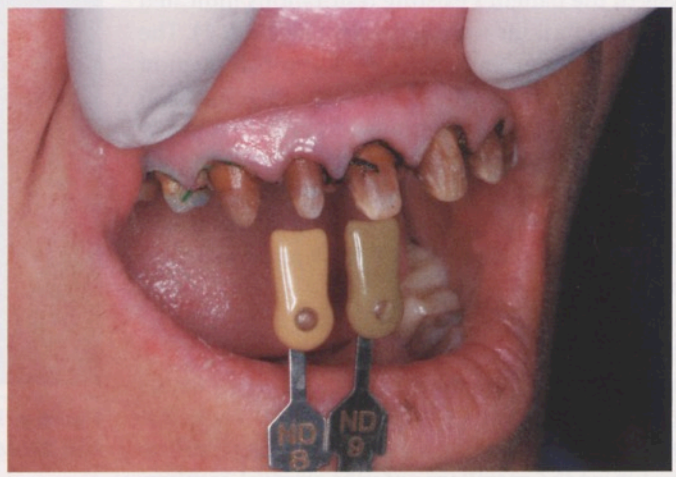


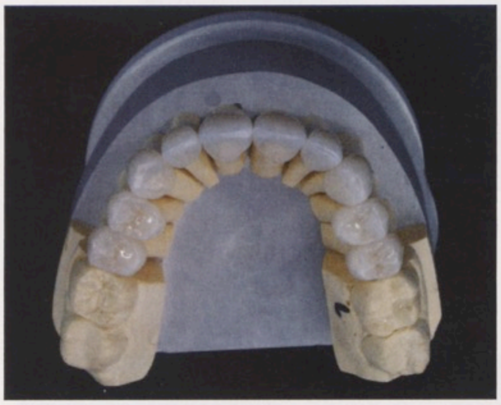
Figure 9: Stump shade revealing the extent of the darkened tooth structure that needed to be blocked out.

macro esthetic elements **(Fig 10)**, impressions and images were taken and sent to the dental laboratory to facilitate the fabrication of the zirconia restorations.

After fabrication, the zirconia restorations were returned to the clinician's office **(Figs 11-13)**. They were tried in to verify fit and occlusion, including compatibility with the patient's envelope of function. Upon verification the restorations were cleaned with Ivoclean; treated with MonoBond Plus; and cemented with Adhese, a universal bonding adhesive, and dual-cure Variolink Esthetic resin cement (all Ivoclar Vivadent) **(Figs 14-17)**.

> "The difficulty in achieving predictable excellent esthetics with PFM restorations and the desire for metal-free solutions has led to the increased use of zirconia..."

Figure 10: Facial view of the patient in provisionals to illustrate the 3D macro smile design elements of the provisional cast.



Figures 11 & 12: Fabricated zirconia restorations on the maxillary and mandibular working models.

Figure 13: Restorations reflecting the intricate synergy between block-out capability and lifelike optical metamerisms needed to mimic natural teeth.

Figures 14-16: Frontal, right lateral, and left lateral post-seating natural smile, 1:2 magnification.

Figure 17: The seated zirconia restorations, retracted 1:2 magnification. Note the reticular lichen planus on the buccal mucosa and the posterior gingiva.

Summary

Due to recent advances in the composition, technical handling and optical properties of zirconia, the dentist-laboratory technician team can restore very dark, stained teeth with restorations that exhibit natural, lifelike optical properties. The ability to restore such a case can have a profound effect on the patient and the entire restorative team.

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