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Evolution and clinical applications of esthetic ceramic materials in dentistry

Stephen J. Chu, DMD, MSD, CDT
Guest Editor

The evolution from metal-ceramic to all-ceramic restorations has been exciting as well as painstaking. In the mid-1960s, McLean and Hughes¹ introduced the metal oxide–reinforced all-ceramic crown.

In the early 1980s, researchers developed a shrink-free alumina core crown^{2,3} (Cerestore, Johnson & Johnson, New Brunswick, N.J.) and a castable glass ceramic, the result of a venture between Dentsply International (York, Pa.) and Corning (Corning, N.Y.) (hence the name Dicor).³ In the early 1990s, leucite-reinforced glass ceramic (IPS Empress, Ivoclar Vivadent, Amherst, N.Y.) was developed, which consisted of leucite crystals in an amorphous glass matrix.^{4,5}

In 2000, researchers developed lithium disilicate materials, which improved the strength of restorations.⁶ In an ongoing effort to create metal-free FDPs, researchers developed zirconium oxide ceramics^{7,8} for which short-term to midterm survival has been reported.^{9–11} Controversial reports have appeared regarding the fracture and chipping rate of bilayered zirconium oxide restorations.¹² In vitro study results of new monolithic ceramic restorations have been impressive¹³ (Figure).

In this supplement, Dr. Silva and colleagues¹⁴ report the results of an in vitro study comparing the fatigue strength of lithium disilicate glass-ceramic (LDGC) crowns with a buccal thin veneer with that of layered zirconium oxide and metal-ceramic crowns. In the same article, Drs. Powers and Farah¹⁴ present clinical survival rates of layered zirconium oxide and LDGC crowns. Also in this article, Dr. Esquivel-Upshaw¹⁴ reports the results of a randomized clinical trial of the wear of monolithic and bilayered LDGC crowns.

Mr. Roberts and Dr. Shull¹⁵ describe the use of bilayered LDGC veneers for esthetic reconstruction in a woman. Dr. Edelhoff and Mr. Brix¹⁶ present clinical cases involving all-ceramic restorations. Finally, Dr. Vargas and colleagues¹⁷ present cementation protocols for various ceramic systems, which are critical to achieving success.

Ceramic technologies will continue to evolve as the demand for high-quality, natural-appearing restorations increases. ■

Dr. Chu is a clinical associate professor and director of esthetic education, Department of Prosthodontics, College of Dental Medi-



Figure. A. Tooth no. 14 with a fractured amalgam restoration. **B.** Same tooth with a monolithic lithium disilicate glass-ceramic partial-coverage bonded onlay immediately after cementation.

cine, Columbia University, New York City. He also is in private practice in New York City. Dr. Chu also is the guest editor of this supplement. Address reprint requests to Dr. Chu, 150 E. 58th St., Suite 3200, New York, N.Y. 10155, e-mail "schudmd@aol.com".

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Comparative reliability analyses of zirconium oxide and lithium disilicate restorations in vitro and in vivo

Nelson R.F.A. Silva, DDS, MSc, PhD; Van P. Thompson, DDS, PhD; Guilherme Bonecker Valverde, DDS, MSc; Paulo G. Coelho, DDS, PhD; John M. Powers, PhD; John W. Farah, DDS, PhD; Josephine Esquivel-Upshaw, DMD, MS

Placement of full-coverage crowns constitutes the most common fixed prosthodontic treatment.¹ To meet the increasing demands of patients and dentists for esthetic, metal-free biocompatible restorations, manufacturers have developed several types of all-ceramic systems during the last few decades.

In comparison with other all-ceramic systems, frameworks composed of yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) (that is, zirconium oxide) exhibit superior mechanical properties, owing, in part, to a transformation toughening process in which the tetragonal form changes to the cubic form with stress, thus limiting crack propagation.^{2,3} However, investigators have described fractures within the veneering ceramic as the most frequent mode of clinical and laboratory failure.⁴⁻¹⁰ About five years ago, a lithium disilicate glass-ceramic (LDGC) (IPS e.max CAD, Ivoclar Vivadent, Amherst, N.Y.) was introduced for computer-aided design/computer-aided manufacturing (CAD/CAM) processing technology. Clinicians can produce restorations to full contour or as a substructure core for subsequent porcelain veneering. This high-strength material offers versatile applications and can be used to fabricate single crowns in the anterior and posterior region with conventional or self-adhesive cementation.

Guess and colleagues¹¹ conducted a study of full-contour LDGC restorations, the results of which were excellent. However, the in vitro and clinical reliability of

ABSTRACT

Background. The authors analyzed the in vitro and in vivo performance of lithium disilicate glass-ceramic (LDGC) restorations and yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) (that is, zirconium oxide) restorations with regard to reliability, clinical performance and abrasion resistance.

Methods. In the in vitro study, four authors subjected samples of LDGC, Y-TZP and metal-ceramic crowns to step-stress fatigue testing. Four investigators assessed the in vivo clinical performance of LDGC and zirconium oxide-based restorations at four and seven years, respectively. In addition, one author conducted a randomized, controlled clinical trial to analyze the volumetric loss of enamel and ceramic antagonist surfaces.

Results. The LDGC crowns exhibited the highest fatigue load-to-failure values in the in vitro analysis. The results of the in vivo assessment showed that the clinical performance of the LDGC restorations at four years was comparable to that of the zirconium oxide-based crowns at seven years. The results of the in vivo, randomized, controlled clinical trial showed that LDGC crowns were not only resistant to wear, but also were wear friendly to enamel antagonist surfaces.

Conclusions. The LDGC crowns in the in vitro and in vivo studies exhibited high durability, and they were wear friendly to opposing natural dentition.

Clinical Implications. LDGC and zirconium oxide-based crowns are a clinically acceptable means of treating teeth that require full-coverage restorations. In addition, LDGC materials exhibit excellent clinical performance, as well as demonstrate acceptable abrasion compatibility with the opposing natural dentition.

Key Words. All-ceramic; lithium disilicate glass-ceramic; zirconium oxide; metal-ceramic; esthetic restoration; in vitro; in vivo; computer-aided design/computer-aided manufacturing. *JADA 2011;142(4 suppl):4S-9S.*

Dr. Silva is an assistant professor, Department of Prosthodontics, New York University College of Dentistry, New York City. Dr. Thompson is chair, Department of Biomaterials and Biomimetics, New York University College of Dentistry, New York City, e-mail "van.thompson@nyu.edu". Dr. Valverde is a visiting scholar, Department of Biomaterials and Biomimetics, New York University College of Dentistry, New York City. Dr. Coelho is an assistant professor, Department of Biomaterials and Biomimetics, New York University College of Dentistry, New York City. Dr. Powers is co-owner of Dental Consultants, publisher of The Dental Advisor, and co-owner of Apex Dental Milling, Ann Arbor, Mich. He also is a professor of oral biomaterials, University of Texas Dental Branch at Houston, e-mail "jpowers@dentaladvisor.com". Dr. Farah is co-owner of Dental Consultants, publisher of The Dental Advisor. He also is co-owner of Apex Dental Milling, Ann Arbor, Mich. Dr. Esquivel-Upshaw is an associate professor, Restorative Dental Sciences, JHM Health Science Center, College of Dentistry, University of Florida, Gainesville, e-mail "JESQUIVEL@dental.ufl.edu".

the material used with veneering porcelain remains to be determined, as well as how the material compares with metal-ceramic restorations (MCRs) and zirconium oxide-based systems. In addition, minimal clinical data are available regarding the in vivo wear of these ceramic materials (veneered and nonveneered) and their effect on the opposing enamel. Clinical measurement of wear poses significant challenges because of patients' variable chewing patterns, variable dietary compositions and complex masticatory movements.

The objective of the in vitro laboratory study was to compare the reliability and characteristic strength of LDGC crowns with buccal thin veneer (BTV) with those of MCRs and Y-TZP-supported ceramic crowns. The objective of the in vivo clinical durability study was to define the clinical survival rates and acceptability of LDGC and zirconium oxide-based restorations at four- and seven-year recall visits, respectively. Last, the objective of the clinical wear study was to compare the volumetric loss of a core ceramic with that of two veneering ceramics, as well as to analyze wear of the opposing enamel and enamel-to-enamel wear.

IN VITRO STUDY

Materials and methods. One author (P.G.C.) generated a CAD-based three-dimensional (3-D) model of a mandibular first molar full-crown preparation (Pro/Engineer Wildfire software, Parametric Technology, Needham, Mass.) with a uniform occlusal preparation reduction of 2.0 millimeters and a proximal wall reduction of 1.5 mm ($n = 21$ for each group [LDGC, MCR and Y-TZP]). He made LDGC crowns by using a monolithic system (IPS e.max CAD) designated here as BTV.

Two of the authors (N.R.F.A.S., G.B.V.) resin cemented (Variolink II, Ivoclar Vivadent) all crowns to aged resin-based composite (Z100 Restorative, 3M ESPE, St. Paul, Minn.) dies (in a procedure described by several authors^{7-9,12}) with a stiffness similar to that of dentin (approximately 15 gigapascals) and stored them in water at 37°C for a minimum of seven days before conducting the mechanical testing.

The investigators mounted specimens in a universal testing machine (model 5566, Instron, Norwood, Mass.) and applied an increasing load to fracture at 1 mm/minute through a tungsten carbide (WC) indenter ($r = 3.18$ mm) on the disto-

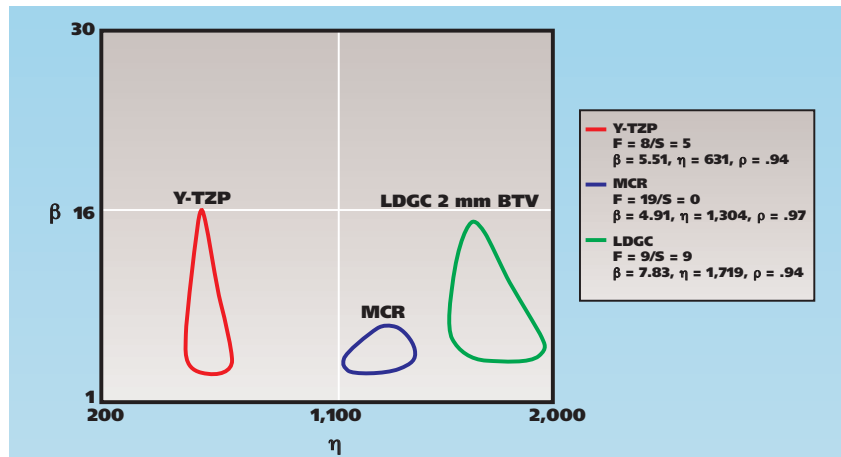


Figure 1. Contour plot of Weibull statistical parameters with 90 percent confidence bounds of β (shape) versus η (characteristic strength) of yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) (IPS e.max ZirCAD, Ivoclar Vivadent, Amherst, N.Y.) crowns,⁹ metal-ceramic restorations (MCR)¹² (Creation Porcelain and White Porcelain Alloy, Jensen Dental, North Haven, Conn.) and lithium disilicate glass-ceramic (LDGC) (IPS e.max CAD, Ivoclar Vivadent) crowns (2-millimeter thickness) with buccal thin veneer (BTV). F: Failed samples. S: Suspended samples.

buccal cusp. Using these data, they exposed the samples to mouth-motion (that is, the indenter was lifted off of the specimen during each cycle) step-stress fatigue.^{7-9,12} The investigators performed fatigue testing with the use of an electro-mechanical machine (EL-3300, Enduratec [now ElectroForce], Bose, Eden Prairie, Minn.). They simulated aspects of natural occlusion by sliding an indenter ($r = 3.18$ mm) 0.70 mm (lingual direction) down the distobuccal cusp, beginning at 0.5 mm lingual to the cusp tip at 2 hertz. At the end of each load-cycle step, the researchers inspected all specimens under polarized light stereomicroscopy (MZ Apo stereomicroscope, $\times 50$, Leica Microsystems, Bannockburn, Ill.) for damage. Four authors (N.R.F.A.S., V.P.T., G.B.V., P.G.C.) compared the results with data collected previously for MCRs (that is, palladium-silver [Pd-Ag]) (Creation Porcelain and White Porcelain Alloy, Jensen Dental, North Haven, Conn.)¹² and with data collected for hand-layered veneered Y-TZP (IPS e.max ZirCAD, Ivoclar Vivadent) crowns (1 mm thick core)⁹ with a 2-mm crown preparation reduction.

Results. The investigators (N.R.F.A.S., V.P.T., P.G.C.) analyzed fatigue data across the groups by using the load at failure. They calculated and compared Weibull statistical parameters with 90 percent confidence bounds shown in Figure 1 as a contour plot, where β is the Weibull shape parameter and η is the characteristic strength at which 63.2

ABBREVIATION KEY. BTV: Buccal thin veneer. CAD/CAM: Computer-aided design/computer-aided manufacturing. LDGC: Lithium disilicate glass-ceramic. MCR: Metal-ceramic restorations. 3-D: Three-dimensional. Y-TZP: Yttria-stabilized tetragonal zirconia polycrystalline.

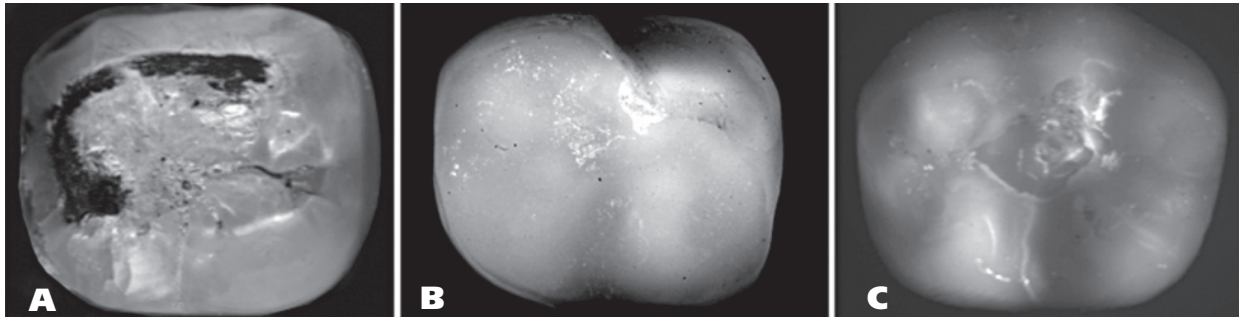


Figure 2. **A.** Fracture of metal-ceramic restoration after fatigue testing. Note the metal coping exposed at fractured site. **B.** Cohesive fracture within veneer porcelain of yttria-stabilized tetragonal zirconia polycrystalline crown. **C.** Test-suspended sample of lithium disilicate glass-ceramic (IPS e.max CAD, Ivoclar Vivadent, Amherst, N.Y.) crown.

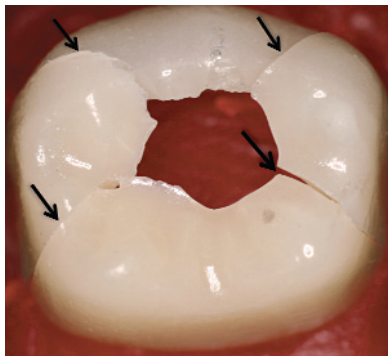


Figure 3. A lithium disilicate glass-ceramic (IPS e.max CAD, Ivoclar Vivadent, Amherst, N.Y.) crown fatigue tested—for the performance of Weibull calculations—until total fracture (arrows) occurred at an extremely high load.

and 7.83 for LDGC. Characteristic strength values (η) were 1,304 newton for MCR specimens and 1,719 N for LDGC specimens. The Y-TZP specimens exhibited the lowest characteristic strength value ($\eta = 631$ N). Masticatory loads are distributed and generally are not above 600 to 700 N.

Failures in the MCR group consisted of veneer fractures exposing the metal core (Figure 2). The chief failure mode for the Y-TZP group was large chips within the veneer porcelain. For the LDGC specimens, the researchers observed ring and cone cracks (surface-initiated cracks that occur in water with sliding contact) at the indentation area at the 400 to 600 N load range that grew slowly with higher loads (Figure 2). When fracture occurred—at loads in the range of 1,400 to 1,900 N—the specimen shattered (Figure 3). This suggests that the growth of cracks at the contact area is limited with IPS e.max CAD, which bears further investigation. We advise caution when making comparisons between multilayer and monolithic systems as part of in vitro studies.

IN VIVO DURABILITY OF ZIRCONIUM OXIDE-BASED RESTORATIONS

The objective of the in vivo clinical durability study was to define the clinical survival and

percent of the specimens are predicted to fail. The absence of overlapping of these bounds indicates a significant difference between groups. The plot (Figure 1) indicates that the Weibull modulus $\beta = 4.91$ for MCR, 5.51 for Y-TZP

acceptability of zirconium oxide–supported and LDGC restorations at seven- and four-year recall visits, respectively.

Materials and methods. Since 2003, one author (J.W.F.) and three other investigators placed more than 1,500 zirconium oxide restorations (Lava Crowns and Bridges, 3M ESPE) with leucite-reinforced veneering ceramic (Lava Ceram Overlay Porcelain, 3M ESPE).¹⁰ These restorations were anterior and posterior crowns, three- to six-unit bridges and implant abutments fabricated by two dental laboratories. The dentists cemented most of the restorations with self-adhesive resin cement (RelyX Unicem Self-Adhesive Universal Resin Cement, 3M ESPE, or another brand).

Results. The investigators recalled 574 restorations (41 percent premolar crowns, 37 percent molar crowns and 22 percent anterior crowns, bridges and implants) at seven years.¹⁰ They provided ratings in four areas (resistance to fracture or chipping, esthetics, resistance to marginal discoloration and wear resistance) on a 1 to 5 scale (1 = poor, 2 = fair, 3 = good, 4 = very good, 5 = excellent). For example, “poor” and “fair” indicate a restoration with fracture or chipping extensive enough to require replacement of the restoration, whereas “good” and “very good” indicate chipping such that the restoration could be polished and did not require replacement.

Figure 4¹⁰ shows the fracture and chipping of zirconium oxide–based restorations at one, three and seven years of service. Of the 574 recalled restorations, 16 (2.8 percent; all molar crowns) were replaced. In many cases, the fractures resulted from delamination of a large portion of the ceramic, and the restoration could not be polished or repaired. None of the fractures involved a zirconium oxide substructural or coping failure. Thirty-five restorations (6.1 percent; molar and premolar crowns) were chipped but did not need polishing or could be polished satisfactorily. Most of the recalled restorations had excellent esthetics (shade matching) and were vital in

appearance (Figure 4¹⁰). The esthetics of zirconium oxide–based restorations are superior to those of MCRs, because the coping can be shaded to act as a good dentin simulator, and the gray color cast of the metal at the cervical area is eliminated.

The investigators rated more than 95 percent of the zirconium oxide restorations as “excellent” for resistance to marginal discoloration (Figure 5¹⁰). During the seven-year evaluation, only 2.8 percent of the restorations exhibited slight graying at the margins, which probably was caused by microleakage. The investigators rated more than 96 percent of the zirconium oxide restorations as “excellent” for resistance to wear. A small number (3.2 percent) of the recalled restorations exhibited some wear of the overlaid ceramic at seven years. The researchers noted minimal to moderate wear in about 15 percent of the teeth opposing the zirconium oxide restorations; this wear was visible mainly in anterior teeth.

IN VIVO DURABILITY OF LDGC RESTORATIONS

Materials and methods. One author (J.W.F.) and three other investigators placed 440 pressed monolithic LDGC restorations (IPS e.max Press, Ivoclar Vivadent) in 260 consenting patients across a four-year period.¹³ Readers should note that IPS e.max Press has properties slightly different from those of IPS e.max CAD, which was assessed in the *in vitro* study. The restorations included crowns, inlays and onlays, and bridges in posterior and anterior teeth; one dental laboratory fabricated all of the restorations. Before cementation, the clinicians etched the internal surfaces of all restorations with 5 percent hydrofluoric acid gel for 20 to 30 seconds, then rinsed and coated them with a silanating agent (Monobond-S, Ivoclar Vivadent). They cemented all restorations with self-adhesive resin or total-etch dual-cured esthetic resin cements that were light-activated to initiate polymerization.

Results. The investigators recalled 236 restorations (37 percent were premolar crowns, 42 percent were molar crowns and 21 percent were anterior crowns, inlays and onlays and bridges).¹³ Approximately one-half of these restorations had been in function for four years, and the other one-half had been in function for three years. They rated the restorations in five areas

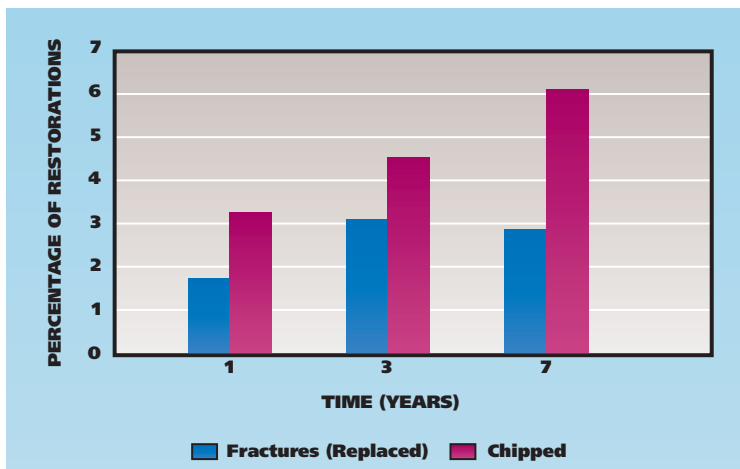


Figure 4. Fracture and chipping of zirconium oxide (Lava Crowns and Bridges, 3M ESPE, St. Paul, Minn.) restorations at one-, three- and seven-year recall visits.¹⁰ Adapted with permission of Dental Consultants, Ann Arbor, Mich., from *The Dental Advisor*.¹⁰

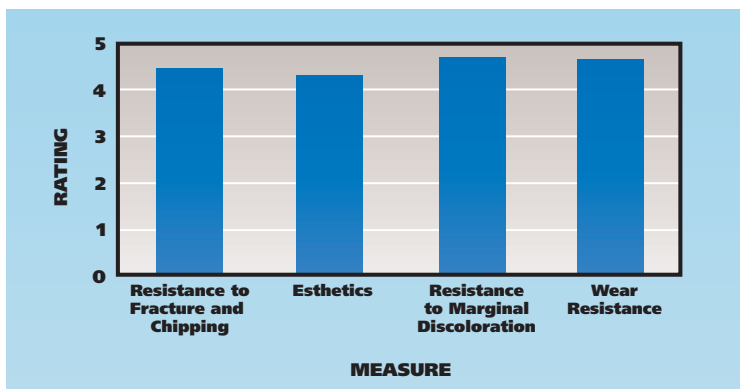


Figure 5. Results of seven-year recall of zirconium oxide (Lava Crowns and Bridges, 3M ESPE, St. Paul, Minn.) restorations.¹⁰ Adapted with permission of Dental Consultants, Ann Arbor, Mich., from *The Dental Advisor*.¹⁰

(esthetics, resistance to fracture or chipping, resistance to marginal discoloration, lack of sensitivity and retention) on a scale from 1 (poor) to 5 (excellent). For example, “poor” and “fair” indicate a restoration with fracture or chipping extensive enough to require replacement of the restoration, whereas “good” and “very good” indicate chipping of the restoration such that it could be polished and did not require replacement.

The investigators rated nearly all of the LDGC restorations as “very good” to “excellent” at recall (Figure 6¹³). The restorations were clinically acceptable and highly esthetic. Owing to limited ingot selection at the time of placement, a few were somewhat opaque and lacked sufficient translucency at placement. Of the 236 restorations recalled, none had fractured or needed to be replaced. Six restorations (2.5 percent)—two onlays and four crowns—exhibited minor chipping at the four-year recall, but none needed to be replaced. In 95 percent of cases, the fit of

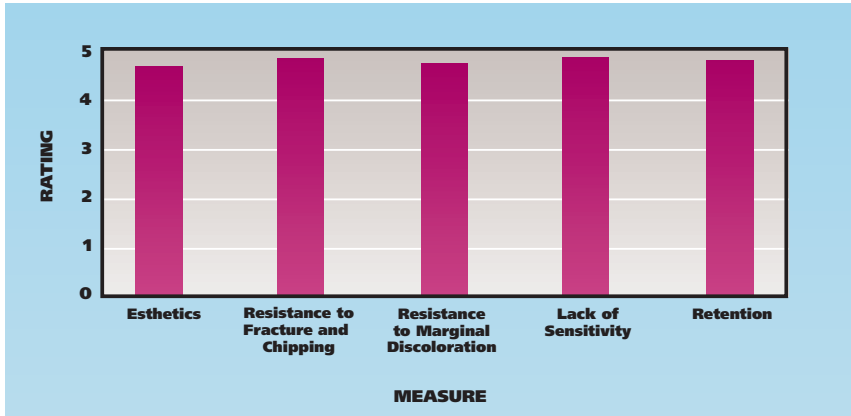


Figure 6. Results of four-year recall of lithium disilicate glass-ceramic (IPS e.max Press, Ivoclar Vivadent, Amherst, N.Y.) restorations.¹³ Adapted with permission of Dental Consultants, Ann Arbor, Mich., from The Dental Advisor.¹³

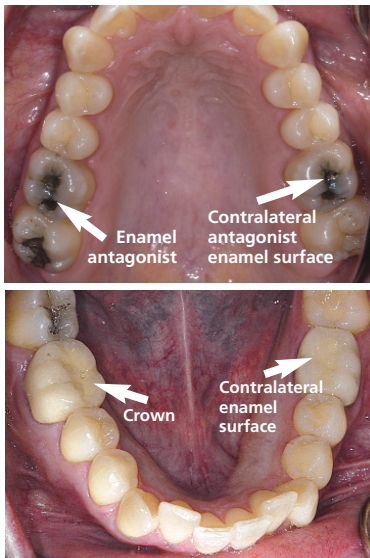


Figure 7. Relative locations of crown and enamel antagonist and the contralateral enamel surface and contralateral antagonist enamel surface.

the restorations was excellent. In 3 percent of the recalled cases, the investigators noted some graying at the margins, but none of the restorations required replacement. Discoloration at the margins probably was related to cementation. Nine restorations (4 percent; molar crowns) had debonded and needed to be recemented.

IN VIVO ANALYSES OF LDGC CORES AND VENEERS

Materials and methods. One of the authors (J.E.-U.) conducted a randomized, controlled clinical trial to analyze the wear of enamel and ceramic antagonist surfaces. This single-masked pilot study involved 31 patients (eight men and 23 women; age range, 24-62 years) with 36 teeth that needed full-coverage crowns opposing natural antagonist teeth. The investigator selected patients primarily because of their need for a single crown on a tooth opposed by an antagonist tooth with intact enamel surfaces (Figure 7). Other criteria were that the enamel surfaces on teeth contralateral to the ceramic crown and the antagonist enamel also were intact to allow measurement of enamel-to-enamel wear, as well as to

assess their overall health.

The investigator randomly assigned 36 teeth to receive a metal-ceramic crown (Argented 62, Argen, San Diego, and IPS d.SIGN veneer, Ivoclar Vivadent) or an all-ceramic crown (IPS Empress 2 core ceramic with IPS Eris for E2 veneering ceramic, Ivoclar Vivadent, or IPS e.max Press core ceramic without a veneering ceramic). Two clinicians (J.E.-U. and another dentist) obtained a vinyl polysiloxane impression (Affinis, Coltene/Whaledent, Cuyahoga Falls, Ohio) from each quad-

rant of the maxillary and mandibular arches to record the occlusal surfaces of the cemented crowns, their antagonist teeth and their contralateral teeth one week, one year, two years and three years after cementation. A dental technician produced the casts with type IV gypsum (GC Fujirock, Leuven, Belgium) and scanned them by using a 3-D laser scanner (es1 Scanner, etkon, Gräfelfing, Germany). Mean volume wear (in cubic millimeters) was calculated by superimposing the baseline one-week image over the first-, second- and third-year images and measuring the loss of ceramic or enamel volume at each of four sites. For teeth containing an amalgam restoration, the restoration was removed from the computation so that only the enamel wear was measured. A statistician used statistical software (SAS PROC MIXED, SAS Institute, Cary, N.C.) to analyze the differences in wear volume.

Results. At year 3, the mean \pm standard deviation volume wear was $1.48 \pm 0.20 \text{ mm}^3$ for IPS d.SIGN, $1.31 \pm 0.17 \text{ mm}^3$ for IPS Eris for E2 and $1.06 \pm 0.12 \text{ mm}^3$ for IPS e.max Press. The natural teeth opposing these ceramic crowns exhibited wear as follows: $1.10 \pm 0.10 \text{ mm}^3$ for IPS d.SIGN; $1.02 \pm 0.20 \text{ mm}^3$ for IPS Eris for E2 and $0.80 \pm 0.09 \text{ mm}^3$ for IPS e.max Press. The enamel-to-enamel wear measured on the contralateral side was comparable to the wear of the natural teeth opposing the ceramic crown. Restorations made of IPS e.max Press exhibited significantly better wear resistance than did the veneer porcelains ($P = .006$). When the investigator considered all teeth, she noted no significant difference between the mean wear of the enamel surfaces in all four quadrants of the mouth ($P = .92$) and no significant difference between the mean wear of enamel and that of either veneer or the core porcelain ($P = .63$).

Discussion. This study is distinctive in that

the investigator measured the wear of enamel opposing ceramic in an in vivo setting and measured the wear of enamel opposing enamel in the same patient. Another notable aspect is that the data show that the core ceramic (IPS e.max Press) is not only wear resistant but also wear friendly to opposing enamel in a manner similar to that of ceramics used for veneering metal-ceramic or all-ceramic crowns. Researchers¹⁴⁻¹⁷ have demonstrated surface changes for low-fusing and conventional porcelain surfaces that varied from selective leaching to total dissolution or a combination of both, influenced by the solution's pH and correlated with biaxial flexural strength.

The results of an in vitro study by Milleding and colleagues¹⁸ indicated that high-intensity corrosion of a glass-ceramic led to the complete washout of alkali and alkaline-earth ions, leaving a silica-rich surface. Similar corrosion produced only a minor surface change in all-ceramic crowns. There is a reasonable likelihood that the dissolution reactions of veneers result in surface modifications that can result in more wear than that of an all-ceramic material with no veneer. The wear resistance of IPS e.max Press might be explained by the fact that this ceramic has the highest reported fracture toughness of the three ceramics assessed in this study.^{19,20} With higher fracture toughness, cracks are arrested and the potential for small cracks to develop on the surface is minimized. These results are promising as researchers continue to explore stronger and more wear-compatible ceramic materials.

CONCLUSIONS

The Weibull statistical parameters calculated after concentrated fatigue loading in the in vitro study showed characteristic strength values for LDGC crowns that were higher than those for crowns in the MCR and Y-TZP groups. The results of a midterm clinical trial showed that zirconium oxide restorations had a 2.8 percent replacement rate across a seven-year period and a chipping rate of 6.1 percent. The same investigators rated the clinical performance of LDGC restorations as "very good" to "excellent" across a four-year period, and they rated the clinical performance of zirconium oxide-based restorations similarly across a seven-year period. Finally, the results of a randomized, controlled clinical trial of LDGC restorations—in which the investigator analyzed the volumetric loss of enamel and ceramic antagonist surfaces—showed that they were wear resistant, as well as wear friendly to the opposing enamel in a manner similar to that of ceramics typically used for veneering metal-ceramic or all-ceramic crowns. LDGC restorations

are not only highly esthetic but also are clinically durable and wear compatible. ■

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Treating a young adult with bonded porcelain veneers

Matt Roberts; G. Franklin Shull Jr., DMD, FAGD

An 18-year-old woman had undergone orthodontic treatment as a young teenager to address the position of her maxillary anterior teeth. Her orthodontist had added composite to her undersized lateral incisors to create an ideal width. After the orthodontic treatment was complete, the orthodontist placed resin-based composite over brown and chalky white areas of the patient's lateral incisors to improve the esthetics.

During the next several years, the patient's previous dentist made multiple conservative repairs (Figure 1), but the patient had become self-conscious about her smile and desired a more predictable long-term solution. One option was to remove the resin-based composite material and redo the bonding; the other option was to place bonded porcelain veneers.¹ When bonded porcelain veneers are preferred, clinicians need to use the most conservative, long-lasting approach.²⁻⁴

The patient's dentist (G.F.S.) informed her of the advantages and disadvantages of both procedures. She opted to receive bonded porcelain veneers and returned to the dental office for a complete oral examination, radiographs, study models, a face-bow, a bite registration, a stick bite and a series of clinical photographs. After reviewing all of the information with the patient, the dentist decided to place six porcelain veneers to accomplish the agreed-upon treatment goals.⁵⁻⁸

ABSTRACT

Background. Esthetic dental treatment for young adults can be challenging. Practitioners often use direct composite bonding in children and teenagers, and often it serves them for many years. However, direct composite bonding has its limitations (such as staining and chipping), and bonded porcelain often is needed.

Case Description. The authors describe an 18-year-old woman who sought esthetic dental treatment. After her dentist discussed treatment options with her, she opted to receive bonded porcelain veneers. The dentist chose a lithium disilicate material on the basis of its strength and esthetic properties. Although the first set of veneers matched the patient's natural teeth well, they did not satisfy her objective of eliminating the white mottling that existed on her natural teeth. Therefore, the dental technician prepared a second set of restorations by cutting back the facial incisal areas slightly in wax to allow creation of incisal effects and by pressing them with a brighter ingot.

Clinical Implications. Collaboration between the dentist and dental technician is essential to achieving treatment success. Likewise, it is important to secure the patient's input during the process, as he or she often has ideas regarding his or her smile that are different from those of the dental team.

Key Words. Bonded porcelain veneers; lithium disilicate material; dental laboratory; esthetic treatment.
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Mr. Roberts is the founder, CMR Dental Laboratory, 185 S. Capitol Ave., Idaho Falls, Idaho 83402, e-mail "info@teamaesthetics.com". Address reprint requests to Mr. Roberts.

Dr. Shull is in private practice, Palmetto Dental Associates, Lexington, S.C.



Figure 1. Preoperative condition of the teeth.

The practitioner then sent this information to a dental laboratory, along with a prescription describing the patient's desires and the dentist's goals. The dentist requested a diagnostic wax-up to facilitate fabrication of the provisional restorations.^{9,10}

PROVISIONAL RESTORATIONS

During the tooth preparation appointment, the dentist administered local anesthetic to the patient and removed the resin-based composite from the six teeth. In preparing the teeth for veneers, the clinician's primary goal was to remove the discolorations but conserve tooth structure (Figure 2). He used a bis-acrylic provisional material in a putty matrix to transfer the wax-up to the mouth. The dentist then removed the bis-acrylic material and inspected it for thin areas. If the reduction had been inadequate, the clinician would have fabricated a new provisional restoration after reducing the thin area further. The dentist then obtained final impressions, a bite registration, a stick bite and photographs of the tooth preparations to communicate preparation colors.¹¹ He spot-bonded the bis-acrylic provisional restorations and refined the occlusion. The patient returned four days later for evaluation of the temporary restorations.

At this appointment, the patient was pleased with the esthetic results and had no complaints. The dentist refined the occlusion, paying close attention to lateral movements to include crossover. He then obtained an impression and photographs of the provisional restorations.

LABORATORY FABRICATION OF VENEERS

The dental technician (M.R.) evaluated photographs of the patient's provisional restorations from an esthetic perspective and mounted models of them, which then underwent a functional analysis. To determine an appropriate



Figure 2. Tooth preparations.

action plan, members of the treatment team discussed any changes needed. In addition, it is important to secure the patient's input at this time, as he or she often has ideas regarding his or her smile that are different from those of the dental team.

After the dentist and dental technician have reviewed the photographs, it is not unusual to decide that small contour changes are needed. If changes in overall tooth position are necessary, the patient will require new provisional restorations that reflect these changes and enable the dentist to evaluate form, function and phonetics. Otherwise, the laboratory moves forward with fabrication of the all-ceramic restorations, which replicate the desired elements of the provisional restorations. The laboratory also makes any slight changes deemed necessary by the treatment team and the patient.

To fabricate the all-ceramic restorations in this case, the dental technician poured and pinned all impressions and mounted the models. He treated prepared tooth dies with a cement spacer and wax separator and then trimmed the margins to allow access. The technician then made a silicone matrix of the approved provisional model and seated it carefully on the model of the prepared teeth.

The laboratory technician then made a small hole in the silicone matrix through the incisal edge of a central incisor. With the matrix seated on the prepared tooth model, he injected the wax through the incisal hole in the matrix and allowed it to cool for three minutes. He then removed the matrix carefully, leaving the wax on the working model. This process transferred the shape and position of the provisional restorations to the final restorations.

The technician then performed any final contouring to create the ideal embrasure form and surface morphology. He also made any required



Figure 3. Try-in of the first set of veneers.

esthetic or functional changes. On completion of contouring, the technician reviewed the clinical photographs to select the ideal ingot for pressing the restorations.

The technician evaluated the color of the patient's underlying dentition by reviewing photographs obtained at the preparation appointment, measured the thickness of the wax-up to estimate the filtering effect and took into consideration the final desired shade when choosing the pressing ingot.¹²⁻¹⁴

Lithium disilicate. We chose a lithium disilicate material (IPS e.max Press, Ivoclar Vivadent, Amherst, N.Y.) on the basis of its strength and esthetic properties. An evaluation of the desired incisal translucency determined the need for, and amount of, incisal cutback to create room for the layered incisal effect. Pressable lithium disilicate demonstrates a flexural strength of 400 megapascals, whereas the layering ceramic exhibits a flexural strength of approximately 90 MPa.¹⁵⁻¹⁸ Therefore, our strategy was to use as much pressable ceramic and as little layering ceramic as possible while achieving the patient's esthetic goals.

In this case, the lack of incisal translucency in the patient's natural teeth led to the use of a monolithic approach (that is, use of a nonlayered material to achieve maximum strength) as described by Okuda¹⁹ and DiMatteo.²⁰ The wax-up was sprued, invested and burned out, after which it was pressed in a dental ceramic oven. The technician then recovered the restorations from the investment via sandblasting and fit them back on the model.

The laboratory technician achieved final contour and surface texture by using diamond burs (Brasseler USA, Savannah, Ga.). The next step was to fabricate composite dies that replicated the color of the prepared teeth, and the technician placed the restorations on the composite

dies to evaluate their color. He applied colored stains to create final effects in the restorations. In this case, the chosen ingot provided the correct color, with little modification required beyond replicating the white surface in the incisal aspect of the patient's natural teeth. This effect was accomplished by using white stain mixed with a glaze paste for durability.

The technician fired this layer to fix its position; he then covered the entire set of restorations with a glaze paste (that is, a thin layer of clear porcelain that internalizes the staining effects) and fired the restorations again. The dental technician fit the restorations to a solid model, paying close attention to the adaptation of contacts and embrasures to the tissue morphology. This prevented the formation of any black triangles between teeth. The technician etched the restorations and delivered them to the dental office for placement.

DELIVERY AND TRY-IN

The patient returned to the dental office for try-in and delivery of the porcelain veneers. The dentist administered anesthetic and removed the provisional restorations by sectioning them with a high-speed handpiece. The clinician cleaned the tooth preparations with chlorhexidine gluconate and tried in the veneers one at a time to verify fit. Once the margins and contacts were confirmed, he used try-in paste to evaluate the esthetics. The patient liked the shape and contours of the veneers, but she did not like the re-creation of the white striated effects. The match to the existing dentition was very good, but it was not what the patient wanted (Figure 3). The dentist obtained more photographs, and fabricated and spot-bonded new provisional restorations. The dental office returned the veneers to the laboratory, with instructions to remake them without the white effects.

REMAKE OF CERAMIC VENEERS

Although the first set of veneers matched the patient's natural teeth well, they did not satisfy her objectives of eliminating the white mottling that existed on her natural teeth and of achieving a brighter smile with incisal translucency. Therefore, a second set of restorations was fabricated, the facial incisal areas of which were cut back slightly in wax to allow creation of incisal effects, while still supporting the incisal edge with the stronger pressed material. The dental technician pressed these restorations as described earlier, but with a brighter ingot.

To produce the patient's desired translucency pattern, the technician used various effect pow-

ders to achieve incisal layering. He performed final grinding of the incisal areas to re-establish contour prior to cutback and glazed the restorations in a ceramic furnace. He etched the restorations and then returned them to the dental office.

SECOND DELIVERY APPOINTMENT

The patient and dental team members approved the second set of veneers on try-in. The clinician cleaned the internal surfaces of the veneers with phosphoric acid and then rinsed, dried and silanated them. He then placed a rubber dam to isolate the anterior segment and prepared the central incisors for bonding. No tissue retraction was needed. The dentist used a total-etch, single-bottle dentin adhesive with a transparent light-cure-only resin cement. He used the spot-cure, clean-up and final-cure technique. The clinician bonded the right canine and lateral incisor next, followed by the left canine and lateral incisor.

After all six veneers were bonded, the dentist removed the rubber dam and refined the patient's occlusion. He polished all adjusted surfaces by using a three-step porcelain polishing system. At a follow-up visit two days later, the dentist checked the patient's occlusion and obtained postdelivery photographs. The patient and dental team were pleased with her new smile (Figure 4).

CONCLUSION

We have presented a case of a young woman who sought dental treatment to improve the appearance of her teeth. After considering her treatment options, she decided to receive bonded porcelain veneers. As this case shows, collaboration between the dentist and laboratory technician is essential to achieving success. Clinicians also need to receive input from the patient during treatment, as he or she often has ideas about his or her smile that are different from those of the dental team. ■

Disclosure. Mr. Roberts has served as a speaker for Ivoclar Vivadent, Amherst, N.Y. Dr. Shull did not report any disclosures.

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Figure 4. Postoperative appearance of the teeth.

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All-ceramic restorations in different indications

A case series

Daniel Edelhoff, CDT, Dr Med Dent, PhD; Oliver Brix, CDT

Clinicians use all-ceramic restorations routinely in dentistry today. The rapid rate of innovation with regard to materials, computer-aided design/computer-aided manufacturing (CAD/CAM) technologies, and intraoral data acquisition systems has resulted in the need for dental care professionals to familiarize themselves with a large body of knowledge to make use of the almost limitless possibilities that these systems offer.

Conventional steps, such as careful treatment planning in collaboration with the laboratory technician, selection of appropriate ceramic materials, and adequate tooth preparation and processing are essential to ensuring the long-term survival of restorations. Furthermore, rapid advances in material technology in the field of glass and oxide ceramics, as well as in adhesive technologies, have led to new treatment options that are reflected in an extended range of indications and in less invasive tooth preparation designs. All-ceramic systems are suitable for a wide range of indications covering almost all areas of fixed restorative dentistry, and they encompass a diverse range of materials.

We present five cases ranging from placement of veneer restorations to complex rehabilitation to illustrate the scope of applications and procedures used to achieve successful outcomes with all-ceramic restorations. Close collaboration between the patient, dentist and laboratory technician is paramount to define and achieve the treatment goals. An analytic wax-up, a diagnostic template derived from the study wax-up and modifiable temporary restorations facilitated communication, decision making and subsequent preparation procedures.

ABSTRACT

Background. Encompassing a vast array of materials, today's all-ceramic systems are suitable for a large range of indications in almost all areas of fixed restorative dentistry.

Methods. The authors describe five clinical cases involving different indications to illustrate the use of different ceramic materials and combinations of materials. They describe the collaboration between the dentist and dental technician for single-tooth restorations and for complex cases, including all stages of the restorative procedures from treatment planning with an analytic wax-up to the selection of appropriate materials, tooth preparation and cementation.

Results. The patients described experienced significant functional and esthetic improvement, even those who had severely discolored teeth. This was possible because the authors executed the working steps in a strictly synchronized manner and selected the restorative materials carefully to meet the specific needs of each patient.

Conclusions. All-ceramic systems have expanded the range of restorative treatment options significantly; at the same time, their handling has been simplified substantially. The use of lithium disilicate glass-ceramic- and zirconium oxide-based frameworks along with an identical veneering ceramic enables the dental care professional to cover almost all indications in fixed prosthodontics while achieving the same esthetic results.

Key Words. Lithium disilicate glass-ceramic; zirconium oxide; fluorapatite veneering ceramic.

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Dr. Edelhoff is an associate professor, Department of Prosthodontics, Ludwig-Maximilians-University, Goethestrasse 70, D-80336 Munich, Germany, e-mail "daniel.edelhoff@med.uni-muenchen.de". Address reprint requests to Dr. Edelhoff. Mr. Brix is owner of Innovative Dental Design, Wiesbaden, Germany.



Figure 1. A. Try-in of veneers in the anterior region of the mandible fabricated on refractory dies by using a fluorapatite-based veneering ceramic (IPS e.max Ceram, Ivoclar Vivadent, Amherst, N.Y.). Preparation was guided by a mock-up, fabricated according to an analytic wax-up. **B.** Postoperative view after definitive placement of the veneers with the use of a multistep dentin adhesive system (Syntac Primer and Syntac Adhesive, Ivoclar Vivadent) combined with a light-curing luting composite for veneers (Variolink Veneer, High Value +2, Ivoclar Vivadent).

VENEERS FABRICATED ON REFRACTORY DIES

Because of their excellent clinical performance, outstanding esthetics and minimally invasive characteristics, resin-bonded veneers offer an excellent treatment option for a wide range of indications.¹ Porcelain veneers are considered advantageous for maintaining tooth vitality and preserving hard tissues,² especially if tooth preparation is guided by a diagnostic template and includes the use of an additive wax-up.³ Full crown preparations require removal of 63 to 72 percent of tooth structure, while veneers require removal of only 3 to 30 percent of tooth structure.⁴

Case 1. A 30-year-old man visited his dentist (D.E.) because of general defects of his tooth structure. The patient requested to have the brightness value of his teeth improved permanently and to undergo esthetic reconstruction to improve the morphology and function of his teeth. After the dental technician (O.B.) created a study wax-up, the dentist and the technician decided to use all-ceramic single-tooth restorations to achieve the patient's treatment goals. The diagnostic template, which had been created on the basis of the wax-up, served as a guide for preparation of the teeth.

The minimum reductions in tooth structure during tooth preparation were as follows: cervical area, 0.4 millimeter; equatorial area, 0.7 mm; and incisal area, 1.2 mm (Figure 1A). The laboratory technician used a fluorapatite-based veneering ceramic (IPS e.max Ceram, Ivoclar Vivadent, Amherst, N.Y.) and layering technique to produce the veneers on refractory dies. The dentist performed try-in by using tooth-colored pastes (Variolink Veneer Try-In Paste, High Value +2, Ivoclar Vivadent), and he performed the final adhesive cementation procedure by using a multistep dentin adhesive system (Syntac Primer and Syntac Adhesive, Ivoclar Vivadent) combined

with a light-curing luting composite for veneers (Variolink Veneer, High Value +2, Ivoclar Vivadent) (Figure 1B).

ALL-CERAMIC INDICATIONS IN THE ESTHETIC REGION

Esthetically demanding cases requiring the use of different all-ceramic framework materials present a challenge for the dental restorative team.

Case 2. A 42-year-old man who exhibited several anterior defects of varying degrees of severity and had lost tooth no. 6 required a functional and esthetic rehabilitation of the maxillary anterior region from tooth no. 5 to tooth no. 11. Because of varying degrees of damage to the teeth and the patient's high esthetic expectations, the treatment team (including D.E. and O.B.) opted to place the following restorations and materials (Figure 2):

- right first premolar to right lateral incisor: zirconium oxide-based three-unit fixed dental prosthesis (FDP) (IPS e.max ZirCAD, Ivoclar Vivadent);
- central incisors: circular prepared veneers with a minimum thickness of 0.3 mm composed of lithium disilicate glass-ceramic (IPS e.max Press, LT, Ivoclar Vivadent);
- left lateral incisor and left canine: full-crown restorations composed of lithium disilicate glass-ceramic (IPS e.max Press, LT).

Because the dental team used the same veneering ceramic (IPS e.max Ceram) for all of the restorations, they were able to achieve a uniform esthetic appearance throughout the dentition. Consequently, an observer would be

ABBREVIATION KEY. CAD/CAM: Computer-aided design/computer-aided manufacturing. **FDP:** Fixed dental prosthesis. **VDO:** Vertical dimension of occlusion.



Figure 2. Different indications for all-ceramic restorations in the esthetic zone of the maxilla: full-crown preparations on teeth nos. 5 and 7 for zirconium oxide–based fixed dental prosthesis; circular veneer preparations for glass-ceramic restorations on central incisors; full-crown preparations for glass-ceramic restorations on teeth nos. 10 and 11.



Figure 3. Try-in of the final restorations fabricated with the IPS e.max (Ivoclar Vivadent, Amherst, N.Y.) all-ceramic system. Zirconium oxide–based three-unit fixed dental prosthesis (IPS e.max ZirCAD) replaced tooth no. 6. Circular veneers (IPS e.max Press, LT framework) on central incisors and full crowns (IPS e.max Press, LT framework) on teeth nos. 10 and 11. An identical veneering ceramic (IPS e.max Ceram) was used for both framework types; consequently, the esthetic appearance of the restorations is the same.

unaware of the fact that various ceramic materials had been used for the frameworks (Figure 3). The clinician used the following luting materials for adhesive cementation of the restorations: primarily chemical curing luting material containing phosphonic and acrylic acid monomers (Multilink Automix, Multilink Primer A and B, Monobond Plus, Ivoclar Vivadent) for the zirconium oxide–based three-unit FDP; light-curing resin cement for the glass-ceramic full veneers (Syntac Primer and Syntac Adhesive, Variolink Veneer, High Value +2, Ivoclar Vivadent) and dual-curing resin cement for the glass-ceramic crowns (Syntac Primer and Syntac Adhesive, Variolink II Base and Variolink II Catalyst, transparent white 110/A, Ivoclar Vivadent).

RECONSTRUCTION OF VERTICAL DIMENSION OF OCCLUSION

Case 3. Tooth wear is an increasing problem all over the world.⁵ A 28-year-old man wanted to improve the esthetics and function of his dentition, which had been damaged severely by abrasive-erosive processes. He complained about experiencing hypersensitivity while eating. In addition, he had noticed that the

shapes of his teeth appeared to be changing increasingly.

The dentist (D.E.) performed an intraoral examination, the results of which revealed severe enamel loss that had led to extensive dentin exposure in the posterior region (Figure 4A). If we assume that the enamel layer should have been at least 1 mm thick in the posterior region, a considerable reduction in the vertical dimension of occlusion (VDO) had already occurred. After eliminating the nutrition-related causes of the erosive processes, the clinician replaced all of the patient’s existing restorations with resin-based composite restorations. This approach allowed the dental team to gain a clear picture of the extent of the defects, the condition of the abutment teeth and the amount of enamel remaining.

After conducting a technical (that is, evaluation of function in static and dynamic occlusion and of tooth proportions in the articulator) and clinical analysis, the dental team and the patient decided on the following treatment plan:

- fabrication of an analytic wax-up to aid the dental team in reconstruction of the esthetics and function of the dentition, as well as for the creation of a transparent, hard elastic diagnostic template (Duran, 0.5 mm, Scheu Dental, Iserlohn, Germany);
- intraoral esthetic evaluation of the wax-up with the help of the diagnostic template;
- transfer of information about the required increase in the VDO gained with the wax-up to a modified Michigan splint to enable the clinician to evaluate the functional effectiveness of the reconstruction;
- preparation of the affected teeth, starting with the opposing quadrants, by using the diagnostic template as a guide and recording the maxillomandibular relationship with the aid of a Michigan splint split in half;
- insertion of the direct temporary restorations fabricated on the basis of the wax-up;
- evaluation of the clinical performance of the temporary restorations on the basis of the analytic wax-up, and any needed adjustments;
- making of impressions and prompt fabrication of final restorations in the dental laboratory;
- try-in and placement of the final all-ceramic restorations.

Treatment began with the patient’s wearing a modified Michigan splint for 12 weeks. During this phase, the required increase in the VDO was transferred accurately to the patient’s oral cavity and was identical with the VDO increase created by the wax-up. In addition, the diagnostic template, which had been fabricated on



Figure 4. **A.** Preoperative view of the combined abrasive-erosive defects on the posterior teeth on the right side of the mandible. The vertical dimension of occlusion (VDO) was affected significantly by severe loss of enamel. **B.** After fabrication of an analytic wax-up and three months' successful therapy with a modified Michigan splint for reconstruction of the VDO, onlays with a minimum thickness of 1 millimeter were fabricated (IPS e.max Press, HT, Ivoclar Vivadent, Amherst, N.Y., with the staining technique). **C.** Postoperative view of the final onlays after adhesive placement with a light-curing low-viscosity resin cement (Variolink II Base, transparent, Ivoclar Vivadent). The onlays exhibited an enamellike appearance and the color adapted well to the surrounding tissues owing to a high degree of translucency.

the basis of the wax-up, enabled the patient to obtain a first impression of the treatment goal.

The diagnostic template served as a guide throughout treatment and as an orientation aid during preparation of the onlays, which the clinician contoured in full anatomical shape by using a lithium disilicate glass-ceramic (IPS e.max Press, HT, with the staining technique) with a minimum thickness of 1 mm (Figure 4B).⁶ As a result, the dentist had to remove little tooth structure in accordance with the intended outer contours of the restorations.⁷ The dentist prepared all teeth and recorded the maxillomandibular relationship at the same appointment.

The clinician fabricated the temporary restorations chairside with the help of the diagnostic template and a bisphenol A-glycidyl methacrylate-based temporary restorative material (C&B Provilink, Ivoclar Vivadent [this product is no longer on the market; the authors now use Telio CS C&B, Ivoclar Vivadent]). In the posterior region, the minimally retentive temporary onlays were left splinted. The clinician placed the temporary restorations with the use of a bonding agent (Heliobond, Ivoclar Vivadent) without any etching of the tooth structure.

The clinician tried in the restorations with the use of a tooth-colored glycerine gel (Try-In Paste, Variolink II) to inspect their shape and shade. He examined the marginal seal and checked the static and dynamic occlusal contacts carefully with the help of a low-viscosity silicone.

Before placing the glass-ceramic restorations, the dentist etched their inner surfaces with hydrofluoric acid (< 5 percent IPS Ceramic Etching Gel, Ivoclar Vivadent) for 20 seconds and then conditioned them with silane (Monobond-S, Ivoclar Vivadent). The clinician used Syntac Primer and Syntac Adhesive on the teeth. He placed all of the onlays by using a single light-curing luting composite (Variolink II Base, shade 110) and used a high-performance curing light (bluephase G2, with > 1,000 milli-

watts per square centimeter, Ivoclar Vivadent) for the final cure. The patient's esthetic expectations were satisfied completely with reconstruction of the lost tooth structure (Figure 4C).

REHABILITATION OF DENTINOGENESIS IMPERFECTA WITH MONOLITHIC POSTERIOR CROWNS

Case 4. A 15-year-old boy visited his dentist (D.E.) together with his parents because he wished to have his severely discolored and mal-formed teeth restored. He said that he was pain free but complained about the severe social stress that he felt because of the appearance of his teeth (Figure 5). After conducting an intraoral examination and obtaining a medical history, the dentist diagnosed the patient as having dentinogenesis imperfecta type II (hereditary opalescent dentin). The specialist dental literature refers to the importance of early therapeutic intervention to stop the destruction of tooth structure and prevent the development of inadequate occlusal function.⁸ Some authors have described the use of all-ceramic crowns as a possible restorative approach and have recommended adhesive cementation.^{9,10} The challenge faced by the dental team in this case was the young age of the patient, who was still growing, and his request for an immediate improvement in his oral condition. In addition, the dental team had to establish an appropriate morphology of the teeth, adjust the VDO and ensure reliable retention of the restorations on the damaged tooth structure.

Against such a background, a study wax-up was created and evaluated with regard to esthetics and function. On the basis of the wax-up, the dental technician (O.B.) manufactured full crowns composed of high-density polymer by using CAD/CAM technology and seated them as long-term (12 months' duration) temporary restorations.

The clinician performed the final restorative procedures section by section, first in the max-



Figure 5. Preoperative view of amber-shaded posterior teeth with extended deformation caused by dentinogenesis imperfecta type II.



Figure 6. Postoperative view of monolithic full crowns (IPS e.max Press, LT, A2, Ivoclar Vivadent, Amherst, N.Y.) made with the staining technique and placed adhesively with a dual-curing resin cement (Variolink II, Ivoclar Vivadent) in a white opaque shade.

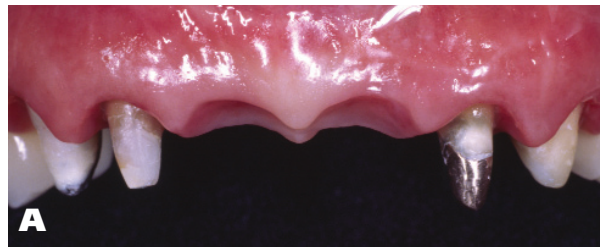


Figure 7. A. Conditioning phase of the ovate pontic recipient sites in the esthetic zone of the maxilla. **B.** Six-unit zirconium oxide-based fixed dental prosthesis with ovate pontics replacing the central incisors.

illa and then in the mandible. In the anterior region, he fabricated the definitive crowns by using a layering technique (IPS e.max Press MO 2/Ceram A2) and in the posterior region, he fabricated the full anatomical crowns by using a pressing and staining technique (IPS e.max Press, LT, A2) (Figure 6).

The prolonged temporary phase provided ample time to test the patient's new VDO, thereby

enabling the treatment team to predict accurately the outcome of the final restorations.

REHABILITATION OF MISSING CENTRAL INCISORS WITH ZIRCONIUM OXIDE-BASED FIXED DENTAL PROSTHESIS

Case 5. A 45-year-old woman visited her dentist (D.E.) because of a trauma to the anterior maxilla. Clinical and radiographic examination revealed deep root fractures of the two maxillary central incisors. Because implants were not the treatment option of choice and all anterior teeth had been restored with metal-ceramic full crowns, the subsequent treatment consisted of preparation of the lateral incisors and canines as abutment teeth, extraction of the two central incisors and insertion of a provisional six-unit FDP, fabricated directly with the aid of a diagnostic template created according to the wax-up.

The dentist conditioned the ovate pontic recipient sites with a relineable long-term provisional restoration (Figure 7A).¹¹ After a healing period of about 12 weeks, the clinician performed the final tooth preparations and obtained precise impressions. The design of the framework included a minimum dimension of 9 square millimeters for the connector cross-section and sufficient support of the veneering ceramic.

During try-in of the final restoration, the dental team paid special attention to ensuring the correct interaction between the ovate pontic recipient sites and the FDP area of the ovate pontics. For esthetic reasons, the clinician reduced the zirconium oxide-based framework (IPS e.max ZirCAD) in the facial cervical aspect of the abutments and applied shoulder veneering ceramic to increase light transmission into the surrounding soft tissues and the tooth structure (Figure 7B). To stabilize the shoulder ceramic, the clinician performed selective etching with hydrofluoric acid and used an adhesive luting material (Monobond Plus, Multilink Automix) for the final insertion. After placement, a harmonious interaction between the soft tissue and the all-ceramic FDP was accomplished.

CONCLUSIONS

Silicate-based all-ceramics have been proven effective in numerous long-term clinical studies as an appropriate material for esthetic single-tooth restorations. They are well suited for a wide variety of applications, from direct layering of veneering ceramics on refractory dies to the veneering of high-strength glass-ceramic frameworks for anterior crowns or extensive

veneer restorations, as well as full anatomical monolithic reconstructions without veneering for posterior inlays, onlays, partial crowns and full-crown restorations.¹²⁻¹⁵ Veneered lithium disilicate glass-ceramic full crowns have demonstrated satisfactory long-term clinical stability in the anterior aspect, as well as in the load-bearing zone.^{16,17} Given their favorable mechanical properties, lithium disilicate glass-ceramic-based restorations seem to require less invasive preparation designs as they exhibit greater strength than do conventional leucite-reinforced glass ceramics.⁶ Furthermore, researchers in clinical midterm (about three years) trials have reported that monolithic lithium disilicate partial-coverage restorations and full crowns offered appropriate stability and did not cause more wear in the opposing dentition than did conventional metal-ceramic crowns.¹⁸⁻²⁰

Polycrystalline ceramics (for example, zirconium oxide) are well suited for restorative components that are exposed to high loads and stress concentrations, such as all-ceramic bridge frameworks and implant abutments.²¹⁻²³ The survival rates of zirconium oxide-based FDPs (up to four units) are promising. However, significant improvement in the veneering system with regard to long-term stability is required.^{14,24} Insufficient data are available regarding FDPs composed of more than four functional units. Therefore, further randomized, controlled clinical trials are needed.²⁴

Our case series demonstrated that virtually all types of fixed restorations—ranging from veneers to bridges—can be accomplished with modern all-ceramic systems. From an esthetic point of view, a single veneering ceramic used for both glass- and zirconium oxide-based framework types has been proven to be advantageous. ■

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Cementing all-ceramic restorations

Recommendations for success

Marcos A. Vargas, DDS, MS; Cathia Bergeron, DMD, MS; Ana Diaz-Arnold, DDS, MS

The longevity and success of indirect restorations are influenced by patient and operator. The patient dictates oral hygiene, diet and functional habits. The operator manages tooth preparation, impression and cementation. Cementation is a crucial step in the process of ensuring the retention, marginal seal and durability of indirect restorations.

Dentistry has benefited from the introduction of new types of ceramics. Better esthetics, increased resistance to fracture, biocompatibility and expanded clinical indications are some of the advantages offered by contemporary ceramics. Because each ceramic is unique in terms of its composition, choosing the appropriate ceramic and cement for each clinical situation can be difficult and confusing. To achieve a successful outcome, the clinician must understand the ceramic type, surface treatment, cementation material and procedure, because the ceramic surface treatment before cementation varies according to the type of ceramic used. In this article, we provide recommendations that can guide clinicians to successful cementation of all-ceramic restorations. (The table summarizes the adhesive cementation procedures discussed in this article.)

CEMENTATION PROCEDURES

Cementing procedures are either adhesive or non-adhesive.^{1,2} Adhesive cementation involves the use of an agent to promote bonding of the restorative material to the substrate; it is a combination of adhesive chemical bonding and micromechanical interlocking. Nonadhesive (conventional) cementation involves the use of a luting agent to fill the space between the restoration and the natural tooth and relies solely on micromechanical retention.³ Indications for each type of cementation are dictated by the composition of the ceramic, the available preparation retention and resistance form, and the field control at the time of cementation.^{4,5} Short, tapered preparations will benefit

ABSTRACT

Background. Several all-ceramic restorative systems of various compositions, properties and indications are available to the dental practitioner. Because of the large number of systems, the dental team faces questions and decisions when choosing the appropriate system and the appropriate means of cementation.

Overview. The authors present a brief overview of the cementation options for various types of all-ceramic restorations. In this article, they discuss the cementation of current all-ceramic restorations and make clinical recommendations tailored to each type of ceramic.

Conclusion and Clinical Implications.

The clinician must have a good understanding of the ceramic type to determine whether a restoration should be cemented adhesively or nonadhesively. Other variables, such as isolation and preparation design, also influence the cementation choice. Various ceramic types demand different surface treatments before cementation. Choosing and applying the appropriate surface treatment and cementation procedure will contribute to long-lasting restorations. The literature is lacking in clinical trial results that validate current in vitro data regarding cementation of all-ceramic restorations.

Key Words. Cementation; dental cements; dental porcelain.

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Dr. Vargas is a professor, Department of Family Dentistry, College of Dentistry, The University of Iowa, S-317 DSB, Iowa City, Iowa 52242-1001, e-mail "marcos-vargas@uiowa.edu". Address reprint requests to Dr. Vargas. Dr. Bergeron is a clinical associate professor, Department of Operative Dentistry, College of Dentistry, The University of Iowa, Iowa City. Dr. Diaz-Arnold is a professor, Department of Family Dentistry, College of Dentistry, The University of Iowa, Iowa City.

TABLE

Summary of adhesive cementation procedures, according to ceramic type.

CERAMIC	FILLER	SURFACE TREATMENT	PRODUCT EXAMPLES
Predominantly Glass	Aluminum oxide	Apply 10 percent hydrofluoric (HF) acid for 1 minute, rinse and dry; apply silane for 1 minute, air dry	Ceramco 3 (Dentsply, York, Pa.), IPS e.max Ceram (Ivoclar Vivadent, Amherst, N.Y.), Vita VM 7 (Vita Zahnfabrik, Bad Säckingen, Germany)
Particle-Filled Glass	Leucite	Apply 5 percent HF acid for 1 minute, rinse and dry; apply silane for 1 minute, air dry	IPS Empress Esthetic (Ivoclar Vivadent)
	Lithium disilicate	Apply 5 percent HF acid for 20 seconds, rinse and dry; apply silane for 1 minute, air dry	IPS e.max Press (Ivoclar Vivadent)
	Glass-infiltrated alumina	Perform air abrasion with tribochemical silica coating or aluminum oxide; apply an adhesion-promoting agent containing MDP* and dry	Vita In-Ceram Alumina, Vita In-Ceram Spinell and Vita In-Ceram Zirconia (Vita Zahnfabrik)
Polycrystalline	Aluminum oxide	Perform air abrasion with aluminum oxide; apply an adhesion-promoting agent containing MDP and dry	Procera Alumina (Nobel Biocare, Zurich)
	Zirconium oxide	Air abrasion with 50-micrometer aluminum oxide powder at 7 pounds per square inch; apply an adhesion-promoting agent containing MDP and dry	Cercon Zirconia (Dentsply), Everest (KaVo, Charlotte, N.C.), Lava Zirconia (3M ESPE, St. Paul, Minn.), IPS e.max ZirCAD (Ivoclar Vivadent)

* MDP: 10-methacryloyloxydecyl dihydrogen phosphate.

from cementation via adhesive techniques, because this process creates a dentin hybrid layer that improves the mechanical retention of the restoration.⁴ However, the use of bonding agents requires additional steps and meticulous isolation, which may not be feasible in the clinical environment. Also, clinicians should ensure that laboratory technicians use precise methods to achieve proper adaptation, because the use of adhesive cements will not compensate for poor fit.

CERAMIC TYPES

When the clinician is selecting the cementation procedure for all-ceramic restorations, it is important that he or she know the composition and structure of the ceramic used to fabricate the restoration. Dental ceramic systems can be classified according to their matrix material, filler and dopant. Three main categories of dental ceramics have been described in the literature: predominantly glass, particle-filled glass and polycrystalline (nonglass) ceramics.^{6,7}

Predominantly glass ceramics. This type of ceramic is derived from feldspar minerals, silicon and aluminum oxides. It is used as a veneering material over metal or ceramic copings and frameworks.^{7,8} Additionally, it is used to fabricate jacket crowns, inlays, onlays and porcelain veneers. This ceramic is highly esthetic, biocompatible, and resistant to abrasion and compressive forces. It also is characterized by low mechanical strength in comparison with other ceramic types and must be cemented

to the prepared tooth adhesively so as to increase the restoration's resistance to fracture.⁹ Thus, nonadhesive cementation is not indicated for feldspathic ceramic.¹⁰

The clinician needs to prepare or "condition" predominantly glass feldspathic ceramics before performing adhesive cementation. The clinician etches the ceramics' intaglio surface with a solution of hydrofluoric (HF) acid, in concentrations between 5 and 10 percent, for approximately one minute. This step provides an increased surface area, micromechanical retention and a clean surface (as described by Navez and colleagues¹¹) for adhesive cementation (Figure 1). The clinician places silane over the etched surface to increase the wettability of the resin cement and to interact chemically with both the resin matrix and the hydroxylated porcelain surface.^{12,13} Both etching and silanation are recommended, as some investigators have reported higher veneer failure rates when ceramic is air abraded and silanated but not etched with HF acid.^{14,15} Hydrolyzed and unhydrolyzed silanes are available. Hydrolyzed silanes most commonly are one-bottle systems with a short shelf life; if the bottle's contents are used after the expiration date, it can be detrimental to the bond.¹⁶ Unhydrolyzed or "inactive" silanes are two-bottle systems that the clinician mixes before application to ensure a fresh and active silane and a longer shelf life than that of

ABBREVIATION KEY. HF: Hydrofluoric. MDP: 10-methacryloyloxydecyl dihydrogen phosphate.

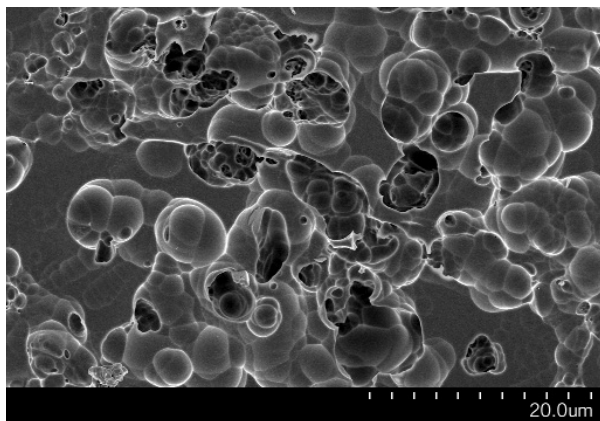


Figure 1. Microscopic view of the surface of a predominantly glass ceramic (Vita VM 7, Vita Zahnfabrik, Bad Säckingen, Germany), etched for one minute with 9.5 percent hydrofluoric acid.

hydrolyzed silanes.^{16,17}

Adhesive cementation to enamel or dentin requires the use of an adhesive system, followed by application of a resin cement.² Adhesive systems can be either self-etching or total etching. Self-etching systems are popular among dentists because they are easy to use, but as a general category they have demonstrated bond strength to enamel weaker than that of total-etch systems.¹⁸ Therefore, the total-etch three-step adhesive system is considered the gold standard. It is imperative to follow the manufacturer's instructions during adhesive cementation, including use of the manufacturer's adhesive and resin cement combination, because investigators have found incompatibilities between some dual-cure resin cements and simplified adhesive systems.¹⁹

Resin cements are polymerized via light, chemicals or a dual process combining the two. Light-polymerized resins are recommended when the ceramic is thin and fairly translucent, allowing the transmission of light through it to reach the resin cement. Examples of light-polymerized cements include Rely X Veneer Cement (3M ESPE, St. Paul, Minn.), Variolink Veneer (Ivoclar Vivadent, Amherst, N.Y.) and Choice 2 Light-Cured Veneer Cement (Bisco, Schaumburg, Ill.). Dual-polymerized resin cements are indicated when the ceramic is too thick or too opaque to allow transmission of light through it.²⁰ Examples include NX3 Nexus Third Generation (Kerr, Orange, Calif.), Rely X ARC Adhesive Resin Cement (3M ESPE) and Variolink II (Ivoclar Vivadent). Chemically polymerized resin cements do not offer much selection in terms of shade and translucency; therefore, dual-polymerized resin cements can be beneficial. Additionally, accessible areas benefit from light polymerization with dual-

polymerized resin cements.²¹

Self-adhesive resin cements have been developed in an attempt to decrease bonding steps and improve ease of use. This approach combines the adhesive and the cement in one step. Examples include Rely X Unicem Self-Adhesive Universal Cement (3M ESPE), SmartCem 2 (Dentsply, York, Pa.) and SpeedCEM (Ivoclar Vivadent). Another approach is to use a self-etching primer before applying the cement, as seen in systems such as Panavia F 2.0 (Kuraray, New York City) and Multilink Automix (Ivoclar Vivadent). Clinicians may choose these cements because of their simplicity and therefore their reduced potential for application errors. Unfortunately, results of *in vitro* investigations have shown that these cements' bond to enamel and dentin is less than that demonstrated by a combination of adhesive systems and resin cements.^{22,23}

Particle-filled glass ceramics. These ceramics consist of various amounts and types of particles and a glassy matrix. The inclusion of particles improves the physical strength of the ceramic. As the number of particles increases and the amount of glass decreases, the material's strength increases, but unfortunately some of the translucency and esthetic properties are diminished. According to their strength, the various materials in this category can be used as veneering material or as copings.⁶

Low-filled materials such as IPS Empress Esthetic (Ivoclar Vivadent) and OPC (Jeneric Pentron, Wallingford, Conn.) are filled with leucite. Their physical strength is relatively low in comparison with that of other filled glass materials, which is why they are indicated mainly for veneers, inlays and onlays, as well as low-stress situations.⁷ These ceramics need to be cemented adhesively to improve their strength.⁹ The cementation procedure is similar to that described previously for the predominantly glass type of ceramic.

Intermediate-filled material, such as IPS e.max Press (Ivoclar Vivadent) and OPC 3G (Jeneric Pentron), is reinforced with lithium disilicate and has strength and pleasing esthetic properties sufficient to allow its use for veneers, single crowns and copings. This material can be cemented adhesively or nonadhesively when used with full-coverage restorations; clinical studies have reported no difference between the two types of cementation.^{24,25} Partial-coverage restorations, such as inlay, onlay and porcelain veneer restorations, require adhesive cementation to increase their retention and fracture resistance. Full-coverage crowns can be cemented conventionally or adhesively

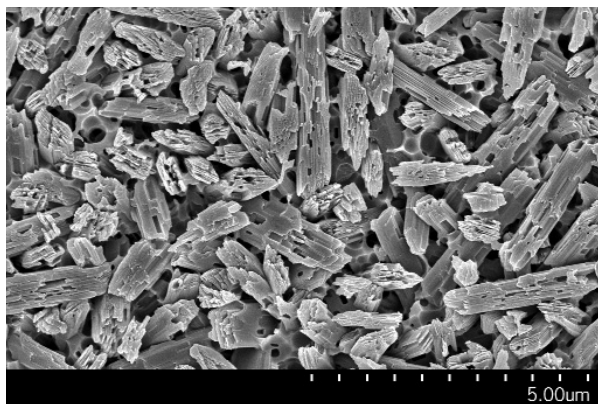


Figure 2. Microscopic view of the surface of a particle-filled glass ceramic (IPS e.max Press, Ivoclar Vivadent, Amherst, N.Y.), etched with 5 percent hydrofluoric acid for 20 seconds.

according to the preparation design. Conventional cementation is carried out with conventional luting agents such as resin-modified glass ionomer cements, without the need for intermediate agents. Short, clinically nonretentive preparations should be cemented adhesively. Another consideration is field control, as it is imperative that the clinician achieve effective isolation to keep the field free of saliva and other contaminants when using adhesive cements. The adhesive cementation of particle-filled glass ceramics is similar to the technique used for predominantly glass ceramics; however, the clinician must modify the process of conditioning the restoration's intaglio surface to achieve optimal adhesion. Manufacturers recommend etching the intaglio surface of leucite-reinforced restorations with a solution of 10 percent HF acid for approximately 60 seconds before cementation. Lithium disilicate-reinforced ceramic should be etched with a solution of 5 percent HF acid for approximately 20 seconds (Figure 2). The clinician then should apply a silane, followed by an adhesive system and a resin cement, similar to the protocol used for predominantly glass ceramics.

Another type of particle-filled glass is made of a sintered core of aluminum oxide infiltrated with molten glass. These ceramics have high strength and fracture toughness with minimal glass content. Some products in this category include In-Ceram Alumina (Vita Zahnfabrik, Bad Säckingen, Germany), In-Ceram Spinell (Vita Zahnfabrik) and In-Ceram Zirconia (Vita Zahnfabrik). They often are referred to as glass-infiltrated aluminum-oxide ceramics. They are cemented conventionally rather than adhesively, because etching glass with HF acid does not appear to increase the retention of resin cements.²⁶ Some researchers have reported that

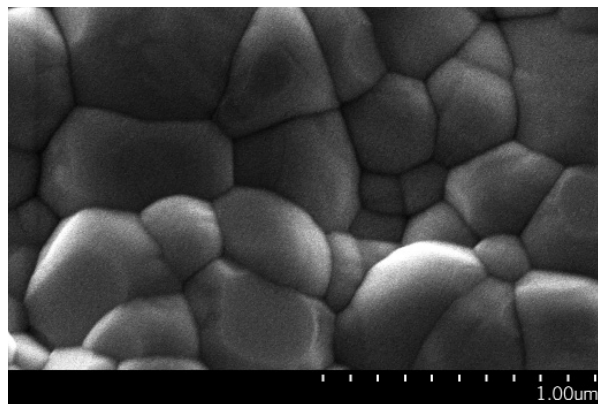


Figure 3. Microscopic view of the untreated surface of a polycrystalline ceramic (Everest, KaVo Dental, Charlotte, N.C.).

coating the ceramic with tribochemical silica and air abrading the intaglio surface, followed by the application of 10-methacryloyloxydecyl dihydrogen phosphate (MDP) (a silane and phosphate monomer) before using resin cement, improves the bond to this type of ceramic.^{27,28}

Polycrystalline ceramics. Polycrystalline ceramics are densely sintered aluminum oxide (Procera Alumina, Nobel Biocare, Zurich) or zirconium oxide (Cercon Zirconia, Dentsply; Everest, KaVo Dental, Charlotte, N.C.; Lava Zirconia, 3M ESPE; Vita In-Ceram YZ, Vita Zahnfabrik; IPS e.max ZirCAD, Ivoclar Vivadent) materials and are characterized by the absence of glass in their composition^{6,7} (Figure 3). Because their atoms are packed into regular arrays, these materials resist the propagation of cracks.²⁹ These ceramics possess high toughness and strength and can be used for copings and frameworks.

Polycrystalline ceramics most often are cemented conventionally but, in certain circumstances, can benefit from adhesive cementation. Investigators have reported the use of air abrasion with aluminum oxide or tribochemical silica application followed by application of an adhesion-promoting agent to increase the bond strength of resin cements.³⁰ Air abrasion increases the available surface area for bonding, yet it also appears to introduce quasiplasticity, as well as microcracks or potential fracture initiation sites. Thus, the use of postsintering surface treatments remains controversial, although low-pressure abrasion has been recommended.³¹ In vitro studies have shown that treating zirconium oxide restorations with a combination of tribochemical silica and MDP or using a primer based on phosphate and carboxylate functional monomers (such as Z-Prime Plus [Bisco]) or a primer combination of MDP and a metal primer (such as Alloy Primer [Kuraray]) enhanced the bond of resin-based

luting cements.³²⁻³⁴ Furthermore, the use of a primer containing MDP (such as Clearfil Ceramic Primer [Kuraray]) without air abrasion improved the in vitro long-term adhesion (150 days with an additional 37,500 thermal cyclings) when compared with conventional cementation.^{31,35} It is believed that these adhesion-promoting agents produce chemical bonds to zirconium oxide.³²⁻³⁴ Therefore, use of air abrasion with 50-micrometer aluminum oxide powder at 7.0 pounds per square inch followed by application of a primer containing MDP before application of the resin cement has been recommended in instances in which increased retention is required.

CONCLUSION

The high demand for esthetically pleasing restorations has resulted in the development and introduction of various dental ceramics. The dentist must choose not only the appropriate ceramic, on the basis of functional and esthetic demands, but also the cement and the cementation procedure for each system and clinical situation. The clinician should give special consideration to the use of adhesives, resin cements and field isolation and adhere strictly to manufacturers' instructions. ■

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