Clinical and Laboratory Considerations for the Use of CAD/CAM Y-TZP–Based Restorations

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Prospective clinical studies are evaluating the long-term success of Y-TZP–based all-ceramic FPDs. Y-TZP–based infrastructures for crowns and FPDs present favorable physical, mechanical, and optical properties. Some Y-TZP–based restorative systems use CAD/CAM technology. Nevertheless, technicians should be able to employ traditional concepts of infrastructure design for both crowns and FPDs when using such materials. The purpose of this article is to review the properties of Y-TZP–based materials as a restorative infrastructure and to review the application of traditional concepts of framework design with CAD/CAM technology.

Learning Objectives:

This article discusses the properties of Y-TZP–based materials as a restorative infrastructure as well as the FPD framework design using CAD/CAM technology. Upon reading this article, the reader should:

- Comprehend the restorative principles involved with CAD/CAM technology.
- Be aware of the role of the crown and FPD infrastructure on longevity and aesthetics.

Key Words: FPDs, Y-TZP, CAD/CAM, infrastructure

Yttrium-tetragonal zirconia polycrystal (Y-TZP)–based materials are currently considered as an alternative to metal alloys for endodontic posts and implant abutments when aesthetics is an overriding consideration.[1-4] Y-TZP–based materials are also being evaluated as an alternative to titanium-based materials for osseointegrated implants[5,6] and as an alternative to metal-ceramics for all-ceramic crowns and fixed partial dentures (FPDs).[7-9]

General Properties of Y-TZP

Yttrium-oxide is a stabilizing oxide that is added to zirconium-oxide (2 mol to 3 mol per hundred) to generate a multiphase material known as partially stabilized zirconia, hence Y-TZP. Tensile stresses acting at a crack tip of a Y-TZP–based infrastructure induce a transformation of the metastable tetragonal zirconium-oxide form into a monoclinic form. This transformation is associated with a local increase of 3% to 5% in volume, which results in the generation of localized compressive stresses around and at the tip of the crack that counteract the external tensile stress acting on the crack's tip. This physical property is referred to as transformation toughening.[10]

The long-term stability of ceramic materials is of primary clinical importance when considering the longevity of all-ceramic restorations. The restoration's stability is closely related to subcritical crack propagation (ie, the continuous crack formation in ceramics that is subjected to static and/or dynamic stress) and stress corrosion (ie, caused by water in the saliva reacting with glass, with resultant decomposition of the glass structure; this leads to increased crack propagation in glass-containing

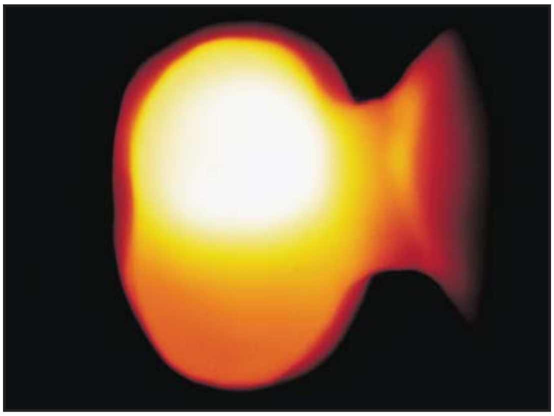

Figure 1. Transillumination of the Y-TZP–based framework demonstrates light transmission through the FPD retainer.

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systems). Since glass-free systems that contain a polycrystalline microstructure (eg, Y-TZP and densely sintered, high-purity alumina) do not present the latter phenomenon, their long-term stability may be enhanced. In vitro studies on Y-TZP samples have demonstrated flexural strengths of 900 MPa to 1200 MPa.[10-12] In vitro studies on Y-TZP–based three-unit FPDs (with different connector dimensions) under static load demonstrated fracture resistance from 1800 N to more than 2000 N. After thermocycling and cyclic-load simulating a five-year clinical load, the fracture resistance under static load was 1457 N.[13-15]

Design and Fabrication of Y-TZP–Based Infrastructures

A Y-TZP–based crown coping or an FPD framework can be designed either using conventional waxing techniques or via computer-assisted design (CAD). The CAD software allows technicians to custom design a framework while combining traditional concepts with material-derived requirements. It is the author's opinion that such software may allow technicians to integrate and use the same data and concepts of design used for conventional waxing techniques. These data include the abutments' shape, dimensions, and position, as well as edentulous ridge dimensions and position, papillae dimensions, the available space for the materials used, and the interocclusal distance.

Once the required data have been obtained, the software must allow application of traditional, custom framework design concepts using virtual waxing. These concepts include cement gap, lingual collar reinforcement, selective coping thickness as determined for different areas of the abutments in order to support the veneering porcelain, pontic position and dimensions (ie, buccolingual width, mesiodistal length, and occlusogingival height), connector width, and connector height.

Figure 2. Preoperative view of a patient missing her mandibular first molars.

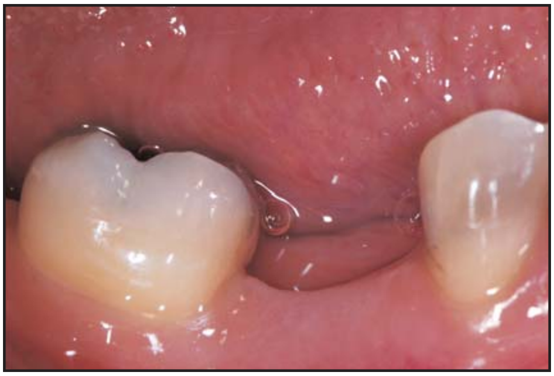

Figure 3. Buccal view of the prospective abutments and edentulous ridges on the right side.

Figure 4. As evident in Figure 3, the occlusogingival height of both edentulous spaces provides adequate connector height for the prospective restoration.

Several Y-TZP–based restorative systems for crowns and FPDs have been described in the scientific literature. While the Cercon system (Dentsply Ceramco, Burlington, NJ) uses conventional waxing to design the Y-TZP–based infrastructure, the DCS Smartfit (Austenal, Chicago, IL) and Lava (3M ESPE, St. Paul, MN) systems use different types of CAD technology with different features and options in terms of the types of infrastructure allowed and their design.[7-9] Once the design of the infrastructure is completed, the data are transferred to a milling unit for fabrication of the framework (either by transferring the data from the CAD unit to the computer-assisted manufacturing [CAM] unit or by scanning a conventional wax pattern). Most Y-TZP–based restorative systems for crowns and FPDs (eg, Cercon, Dentsply Ceramco, Burlington, NJ; Lava, 3M ESPE, St. Paul, MN) use partially sintered Y-TZP–based blanks for milling the infrastructures, whereas the infrastructures for alternative systems (eg, DCS Smartfit, Austenal, Chicago, IL) are milled from fully sintered Y-TZP–based blanks.[7-9] The partially sintered milled infrastructures, which size has been increased to compensate for shrinkage (20% to 25%) that will occur during final sintering, are fully sintered and fitted to the master cast.

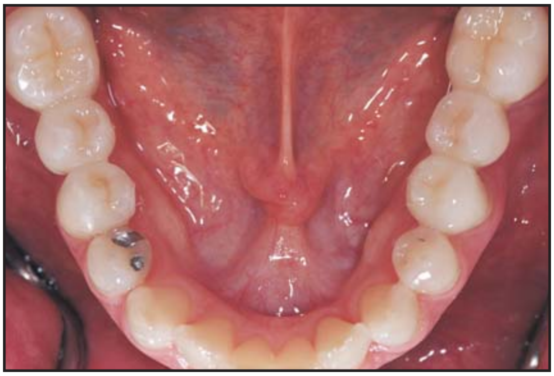

Figure 5. The provisional restorations are used as an adjunct in material selection for the prospective restoration.

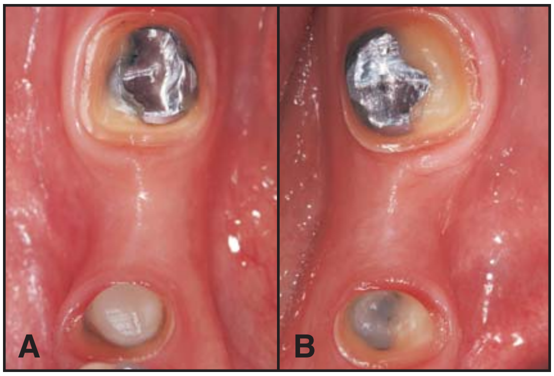

Figure 6A. Occlusal view of the abutments prepared for the Y-TZP–based all-ceramic FPDs. 6B. Note the circumferential rounded shoulder finish line.

The indications and limitations of the Lava system are related to both the properties of its Y-TZP–based infrastructure material as well as the features of its CAD/CAM technology. Some of these material properties and technology features are also shared by other Y-TZP–based restorative systems.

Strength

The aforementioned physical and mechanical properties of Y-TZP–based materials and the glass-free polycrystalline structure contribute to the high strength of the infrastructure. These characteristics may promote the longevity of Y-TZP–based restorations.[10-15]

Biocompatibility

The biocompatibility of infrastructure materials will affect the supporting tissues and may have adverse systemic effects. Y-TZP–based materials have been evaluated in both in vitro and in vivo studies, and no local or systemic adverse reactions have been reported.[16-18]

Radiopacity

In contrast to various all-ceramic materials that present dentinlike radiopacity, Y-TZP–based materials present metallike radiopacity. This property enhances radiographic evaluation of Y-TZP infrastructures in terms ofmarginal integrity during the FPD framework try-in, facilitates complete excess cement removal, and improves prospective follow-up and evaluation of the restoration for recurrent proximal decay.

Low Thermal Conductivity

Metal alloys, which are used in metal-ceramic restorations, have high thermal conductivity. Contemporary ceramic materials provide low thermal conductivity, which leads to less thermal sensitivity and reduced pulpal irritation.

Favorable Marginal Placement

Traditional metal-ceramic preparation guidelines (eg, rounded line angles and finish lines) are recommended for these restorations. The finish line may be placed either at or slightly below (ie, 0.5 mm) the free gingival margin whenever possible without compromising the aesthetic result.[9] This will then promote the health of the supporting tissues and facilitate impression procedures.

Conventional Cementation

With Y-TZP–based materials, adhesive cementation is not mandatory and conventional cementation procedures can be used.[9] Excess cement removal is facilitated as well. Adhesive cementation may be technique-sensitive, particularly if the finish line is placed relatively deep into the gingival sulcus due to the presence of previous restorations with subgingival margins, subgingival decay or core build-up, or the need to enhance retention. In these cases, adequate moisture control may not be accomplished, leading to compromised adhesion and reduced longevity of the restoration.

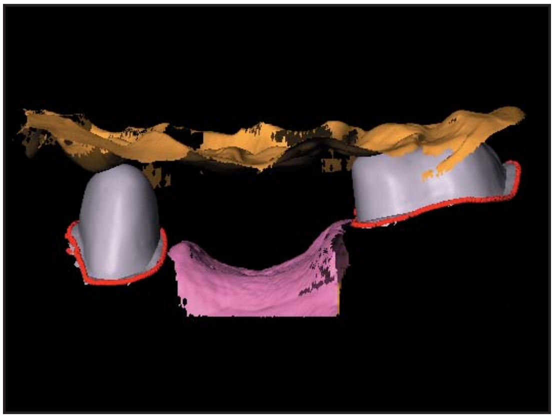

Figure 7. Buccal view of the virtual retainers, edentulous ridge, and interocclusal record.

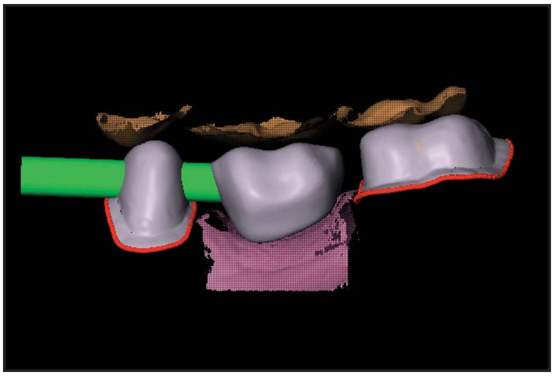

Figure 8. The virtual mesial connector is custom-designed. A mesial connector is selected and modified.

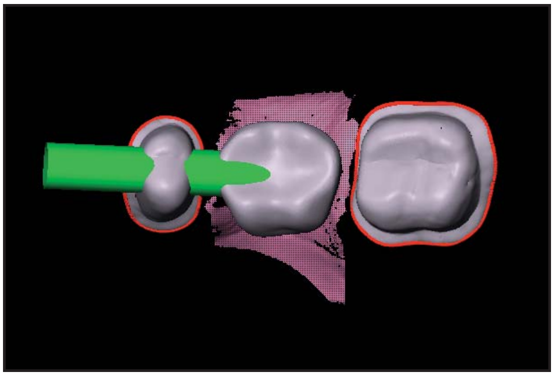

Figure 9. The mesial connector is widened buccolingually to achieve more than the minimum critical surface area.

Small Connector Surface Area

As compared to some other all-ceramic systems for FPDs, the Y-TZP–based system presents with a relatively small connector surface area. The minimum critical connector surface area for the Lava framework is 9 mm^2, a dimension that may be comfortably achieved in many clinical scenarios.[9]

Enhanced Aesthetics

Many Y-TZP–based systems present a white, opaque infrastructure that may limit the restoration's aesthetic potential; the Lava Y-TZP infrastructure may demonstrate increased translucency and a masking ability that facilitates coverage of metal cores or discolored teeth (Figure 1). The infrastructure can be colored into one of eight shades (corresponding to the Vita-Lumin shade guide) prior to the final sintering procedures. This feature allows the clinician to develop the shade of the restoration from the prepared tooth via the intaglio surface of the infrastructure through the external aspect of the veneering porcelain. This ability to control the shade of the framework may further eliminate the need to veneer the lingual and/or the gingival aspects of the FPD connectors in cases where interocclusal distance is marginal and the required connector dimensions are barely achieved.

Custom Infrastructure Design Using Virtual Waxing

Use of CAD/CAM technology follows initial conventional laboratory procedures. Once the sectioned pinned dies, edentulous ridge, and interocclusal record are scanned, all the parameters required for a traditional framework design are entered into the computer. Additional patient and clinician information and specifications (eg, cement space, lingual collar reinforcement, coping thickness, shade of framework) are entered into the patient's data file as well. These features, combined with the ability to

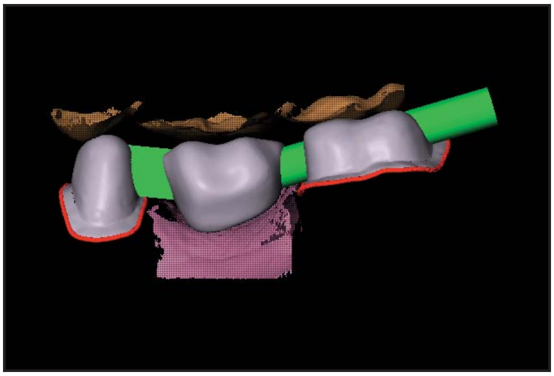

Figure 10. The virtual distal connector is custom-designed. A distal connector is selected and modified to achieve more than the minimum critical surface area.

1) select an acceptable pontic from a corresponding file, 2) position and modify it as required, and 3) design the connectors, promote a custom design of the infrastructure using concepts applied by the technician in daily practice when using traditional waxing techniques.

Automatic Finish-Line Detection and Quality Control

The software enables automatic finish-line detection and allows users to manually adjust for errors. If the minimum critical connector surface area cannot be achieved while designing the FPD framework, the software does not allow the data to be transferred to the milling unit, and a framework lacking the required specifications cannot be fabricated.

Milling a Partially Sintered Blank

Similar to other Y-TZP–based restorative systems, a uniform framework is milled from a partially sintered Y-TZP blank with minimal damage to the microstructure of the material. As compared to milling from a fully sintered Y-TZP blank, milling time is shortened and wear and tear of hardware is reduced.

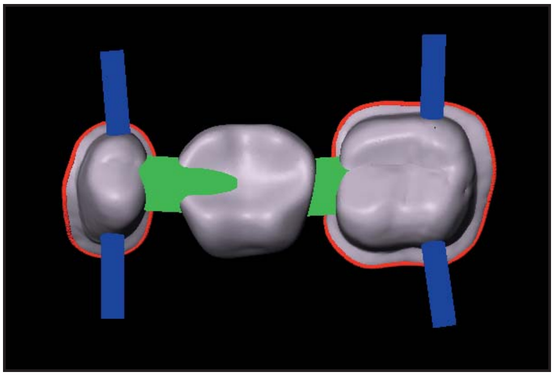

Figure 11. The completed virtual waxing and virtual sprues are ready to be sent to the milling unit.

Figure 12. Buccal view of the Y-TZP framework seated intraorally.

Marginal Fit

In vitro studies have been performed to evaluate the marginal integrity of Lava Y-TZP–based infrastructures. The first study demonstrated a marginal gap of 72 μm ± 36 μm for crown copings; a second exhibited a marginal gap of 59 μm ± 21 μm for FPD frameworks.[19-21]

Restorative Applications

Single- and three-unit blanks are currently available for the fabrication of anterior and posterior crowns and three-unit FPDs similar to other Y-TZP–based restorative systems. Four-unit blanks will soon be available.

Indications

The system is indicated for:

- Anterior crowns;
- Posterior crowns;
- Anterior three-unit FPDs;
- Posterior three-unit FPDs; and
- Implant-supported crowns and FPDs.

Limitations

The limitations of the system are primarily related to the use of the system for FPDs:

Figure 13. Open gingival embrasures were provided for adequate oral hygiene maintenance.

- *Restricted Interocclusal Distance*
  Using the restorative system when the interocclusal distance is restricted is not recommended. In such a case, it may be difficult to achieve the required connector surface area without compromising the health of the supporting tissues.[22]
- *Heavily Stressed Connectors and Bruxism*
  Heavy stresses at the connector area will increase the risk of a catastrophic fracture. Therefore, the use of the system is questionable for cantilever FPDs and periodontally involved abutment teeth that exhibit increased mobility. Due to the lack of clinical data at this point, when a patient is a heavy bruxer, an alternative type of restorative system should be considered.
- *Restricted Infrastructure Design*
  The current generation of CAD software allows custom design of the framework for the majority of clinical scenarios with a uniform thickness. A second generation of CAD software that allows selective thickness in different areas of the coping/retainer has also been developed, thus allowing increased flexibility in terms of infrastructure design, reducing the probability of unsupported veneering porcelain.
- *Limited Clinical Data on the Survival of the Restorations*
  Prospective clinical studies evaluating the survival of posterior three-unit FPDs are being conducted, though only short-term data are currently available. A two-year follow-up of 38 posterior three-unit Lava FPDs that were conventionally cemented demonstrated no failures but a minor chipping of the veneering porcelain of one FPD.[23]

Clinical and Laboratory Procedures

Diagnosis

A minimum critical connector surface area of 9 mm^2 is necessary for Lava Y-TZP–based FPDs. The available space for the prospective connectors must be evaluated (in terms of prospective height and width) prior to selecting the restorative system by measuring from the base of the sulcus to the marginal ridge and by measuring the width of the edentulous ridge adjacent to the marginal ridge (Figures 2 through 4).[22] The space for the connector may often be restricted due to a reduced interocclusal distance. In these instances, it may be difficult to achieve the required connector dimensions without compromising the biologic demands of open embrasures for facilitating plaque control and oral hygiene and for maintaining healthy papillae.[24,25] In addition to the clinical evaluation, the prospective connector dimensions may be further evaluated with measurements made with the diagnostic waxup and the shells or templates fabricated for the provisional restorations (Figure 5). Since the Lava Y-TZP–based framework can be colored into one of eight different shades, the clinician may select the basic shade for the framework at this point.

Preparation and Impression Procedures

The recommended preparation design is similar to that of metal-ceramic restorations, albeit with the following specifications:

- For anterior crowns and FPD retainers, approximately 1.5 mm to 2 mm of incisal reduction, 1 mm to 1.5 mm of lingual reduction, and 1 mm to 1.5 mm of facial reduction are recommended;
- For posterior crowns and FPD retainers, occlusal reduction of 1.5 mm to 2 mm and axial reduction of 1 mm to 2 mm are recommended;
- A 4° minimal taper is required to allow the scanner an adequate reading of the master dies;
- All line angles should be rounded, and sharp edges and/or undercuts must be avoided; and
- Either rounded-shoulder or a chamfer is the finish line of choice (Figure 6).

Standard impression procedures, with the clinician's preferred material and technique of choice, are recommended. An interocclusal record should be obtained to promote adequate framework design.

Fabrication of Master Cast and Scanning

A master cast with sectioned removable dies is fabricated in the conventional manner with light-colored high-strength stone. Dies should be ditched below the finish line. Since reflective areas on the dies are detrimental to the scanning procedure, the use of die-hardener and die-spacer and marking of the margins with a pencil should be avoided. The scanning unit consists of the noncontact, optical scanning system that uses white light triangulation. The sectioned model

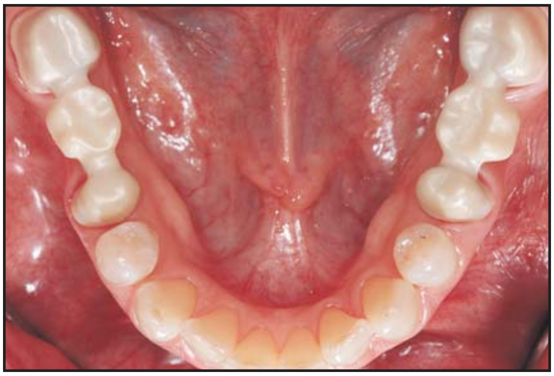

Figure 14. Occlusal view demonstrates connector width and blending of the frameworks with the adjacent dentition. Note how their masking ability conceals amalgam under the distal abutments.

Figure 15. Definitive Y-TZP restoration demonstrate the aesthetic capabilities of the veneering porcelain in terms of shade, translucency, and internal characterization.

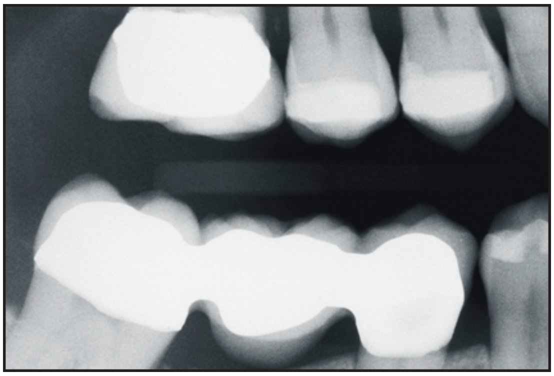

Figure 16. Radiograph shows the seating of the definitive CAD/CAM restoration.

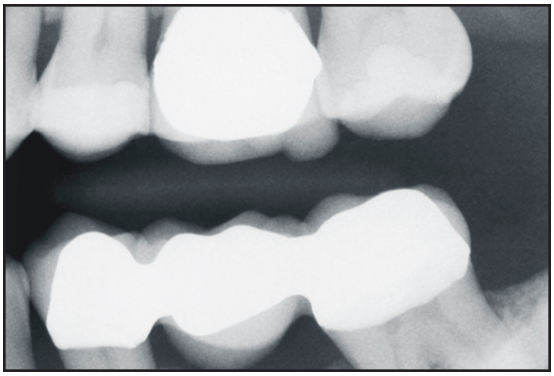

Figure 17. Radiograph of the definitive restoration. Note the metallike radiopacity of the restoration and its excellent fit.

Figure 18. Full-arch occlusal view of the definitive restorations.

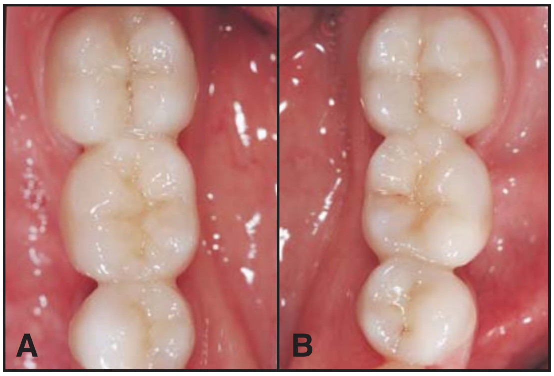

Figure 19A. Occlusal view of the completed restoration. 19B. Postoperative view demonstrates blend of the CAD/CAM restoration with the surrounding tissues.

is mounted on a holding device in the scanner and the individual preparations, edentulous ridge, and interocclusal record are scanned automatically, digitized, and displayed on the monitor as a three-dimensional image (Figure 7). Abutments' finish lines are detected and displayed automatically.

Framework Design and Manufacturing

A minimal coping thickness of 0.5 mm is currently recommended. Coping thickness, cement space, and lingual collar are selected for reinforcement. A pontic is selected from a file and positioned in relation to the retainers, edentulous ridge, and opposing dentition. The connectors are designed in relation to the retainers, pontic, supporting tissues (ie, interproximal papillae), and opposing dentition, while achieving at least the minimum critical surface area (Figures 8 through 10). Once approved, the data are transferred to the milling unit for calculation of the milling path (Figure 11). The software calculates the dimensions of the prospective partially sintered framework in a manner that will compensate for its anticipated shrinkage during the final sintering. Therefore, an enlarged framework is designed and milled. Three types of burs (ie, rough milling, finishing, and fine finishing) are used for milling the framework. Shape correction and surface finishing procedures are performed at this stage. Sharp corners, edges, the intaglio surface of the connectors, and all areas on the surface should be finished and smooth prior to sintering. Once finished, the framework is colored according to the selected shade and fully sintered. The fit should then be verified on the master cast.

Framework Try-in and Veneering

The CAD/CAM-derived framework is tried in to evaluate fit and marginal integrity with a silicone-based disclosing paste. If a pressure area is detected, the abutment tooth is adjusted at the corresponding area with a high-speed diamond bur. If minor adjustment cannot eliminate an existing misfit, a new impression must be made (Figures 12 through 14). The Lava Ceram veneering porcelain (3M ESPE, St. Paul, MN) is designed to match the framework in terms of physical as well as optical properties. The coefficient of thermal expansion of the veneering porcelain is closely matched (ie, −0.2 ppm) to that of the Y-TZP framework. The 16-shade layering system is based on the Vita Lumin range with the addition of special effect and stain materials and has natural translucency that harmonizes with the translucent framework (Figure 15).

Restoration Try-in and Cementation

The completed restoration is tried in, evaluated, and adjusted in the following sequence: proximal contact-points, retainer's and pontic's intaglio surface for marginal fit, and occlusal contacts. Cementation is facilitated and simplified using conventional cementation procedures, and radiographs are taken to verify removal of excess cement (Figures 16 through 19).

Discussion

Y-TZP–based materials are emerging as all-ceramic restorative materials in dentistry due to their mechanical properties and biocompatibility. Initial results of ongoing clinical studies evaluating success of Y-TZP–based FPDs are encouraging. One clinical study evaluating 59 Cercon (Dentsply Ceramco, Burlington, NJ) three- and four-unit, conventionally cemented, posterior FPDs demonstrated chipping of the veneering porcelain in two FPDs at an average 18-month follow-up.[26] In a second clinical study, evaluating 44 Cercon (Dentsply Ceramco, Burlington, NJ) three- to five-unit posterior FPDs demonstrated no framework fractures. Of the FPDs placed in this clinical study, 7 were replaced due to fracture of the veneering porcelain, loss of retention, or biological complications.[27] Another recent clinical study that evaluated 38 Lava (3M ESPE, St. Paul, MN) three-unit, conventionally cemented, posterior FPDs demonstrated chipping of the veneering porcelain in two FPDs at an average two-year follow-up.[28]

Conclusion

From a technical standpoint, the inherent properties of the Y-TZP–based infrastructure and the inherent advantages of the CAD/CAM concept, may contribute to simplified fabrication of an aesthetic and functional infrastructure. Furthermore, clinicians may have the ability to provide patients with metal-free restorations in a relatively simple manner using metal-ceramic–like preparation designs, conventional radiographic evaluation, and conventional cementation procedures. Clinicians must bear in mind the limitations of such restorations and adequate diagnosis is required to maintain high success. Although in vitro data and anecdotal evidence are promising, long-term results of ongoing prospective clinical studies are required to further evaluate the long-term survival of posterior Y-TZP–based FPDs.

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Continuing Education (CE) Exercise No. 18

18 CONTINUING EDUCATION

To submit your CE Exercise answers, please use the answer sheet found within the CE Editorial Section of this issue and complete as follows: 1) Identify the article; 2) Place an X in the appropriate box for each question of each exercise; 3) Clip answer sheet from the page and mail it to the CE Department at Montage Media Corporation. For further instructions, please refer to the CE Editorial Section.

The 10 multiple-choice questions for this Continuing Education (CE) exercise are based on the article "Clinical and Laboratory Considerations for the Use of CAD/CAM Y-TZP–Based Restorations," by Ariel J. Raigrodski, DMD, MS. This article is on Pages 469-476.

1. The flexural strength of Y-TZP–based ceramics, as demonstrated in bending tests, ranges from:
a. 600 MPa to 800 MPa.
b. 900 MPa to 1200 MPa.
c. 300 MPa to 450 MPa.
d. 80 MPa to 120 MPa.

2. What does transformation toughening, a physical property of Y-TZP, cause?
a. Local *decrease* of 3% to 5% in volume that results in localized compressive stresses around a developing crack tip.
b. Local *decrease* of 3% to 5% in volume that results in localized tensile stresses around a developing crack tip.
c. Local *increase* of 3% to 5% in volume that results in localized compressive stresses around a developing crack tip.
d. Local *increase* of 3% to 5% in volume that results in localized tensile stresses around a developing crack tip.

3. Which of the following porcelains is NOT subject to stress corrosion?
a. Glass-infiltrated.
b. Feldspathic.
c. Polycrystalline.
d. None of the above.

4. The radiopacity of Y-TZP infrastructures is similar to:
a. Enamel.
b. Dentin.
c. Feldspathic porcelain.
d. Metal alloys.

5. What are the data and concepts of design used for conventional waxing techniques?
a. Edentulous ridge dimensions and position.
b. The abutments' shape, dimensions, and position.
c. Papillae dimensions, available space for materials used, and the interocclusal distance.
d. All of the above.

6. Contemporary ceramic materials provide which of the following:
a. Reduced pulpal irritation.
b. Low thermal conductivity.
c. Less thermal sensitivity.
d. All of the above.

7. Y-TZP–based restorations can be permanently placed using which of the following procedures?
a. Adhesive cementation only.
b. Conventional cementation only.
c. Either conventional cementation or adhesive cementation.
d. None of the above.

8. To compensate for prospective shrinkage of partially sintered milled infrastructures at the final sintering, the Y-TZP–based framework is designed and milled with what dimensions?
a. 5% to 10% larger.
b. 10% to 15% larger.
c. 15% to 20% larger.
d. 20% to 25% larger.

9. The recommended finish line for Y-TZP–based restorations is:
a. A shoulder only.
b. A chamfer only.
c. A shoulder and a chamfer.
d. A rounded shoulder or a chamfer.

10. What would be the advantages of the radiopacity presented by Y-TZP–based restorations?
a. Enhances radiographic evaluation of Y-TZP infrastructures in terms of marginal integrity during the FPD framework try-in.
b. Facilitates complete excess cement removal.
c. Improves prospective follow-up and evaluation of the restoration for recurrent proximal decay.
d. All of the above.