Glass-Infiltrated Zirconia/Alumina-Based Ceramic for Crowns and Fixed Partial Dentures: Clinical and Laboratory Guidelines

*Edward A. McLaren, DDS**
*Shane N. White, BDentSc, MS, MA, PhD***

Increased patient demands for esthetics and metal-free restorative options have led to widespread use of all-ceramic restorations.[1–3] Porcelain is the material of choice for the esthetic veneering of metal-ceramic or all-ceramic crowns.[3] Porcelain, like all dental ceramics, is stable, inert, and highly biocompatible, and its smooth surface favors gingival health. Recent advances in all-ceramic technology have broadened alternatives for the esthetic reconstruction of teeth. High-strength ceramics and adhesive luting techniques, with their proven clinical success, are now widely used.[4,5]

Although many all-ceramic systems are strong enough to be used on anterior teeth, few all-ceramic systems have been strong enough to perform well on posterior teeth or as fixed partial dentures (FPDs). Posterior teeth are exposed to much greater masticatory and parafunctional forces than anterior teeth. Early all-ceramic materials, including reinforced porcelains, had inadequate mechanical properties and consequently had high rates of catastrophic fracture. Glass-ceramics, eg, Dicor and Empress, contain increased crystalline reinforcement within their glassy matrices compared with conventional feldspathic ceramics. These improved materials tended to have more even distributions of their crystalline reinforcement and smaller crystal sizes, which resulted in higher strength.[6,7] However, strength improvements are limited by the inherent weakness of the glass matrix, because glasses undergo brittle fracture by rapid crack propagation at low critical strains.[8] Acid etching and cementation with adhesive resins helps to resist crack propagation.[5,9] Recently, two strategies have

---

* Director, Center for Esthetic Dentistry, UCLA School of Dentistry, Los Angeles, California.

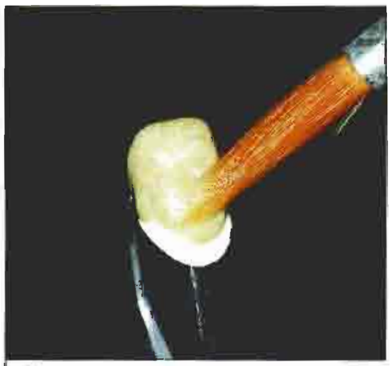
** Research Assistant Professor, Center for Craniofacial Molecular Biology, University of Southern California School of Dentistry, Los Angeles, California.

Reprint requests: Dr Edward A. McLaren, UCLA School of Dentistry, CHS B3-023, 10833 Le Conte Avenue, Los Angeles, CA 90095.

1

2a

2b



3

Fig 1 Buildup of slip onto refractory die material.

Fig 2a Machining of a coping from a premanufactured block of material on a Celay (Vident) CAD/CAM machine.

Fig 2b Milling apparatus of a Cerec (Sirona) CAD/CAM machine, which can mill In-Ceram Spinell, Almina, and Zirconia copings.

Fig 3 Infiltration glass is applied to the sintered coping.

been used to make further improvements in strength. The first strategy was to make the reinforcing component form a continuous skeleton-like meshwork, capable of stopping crack growth. This strategy was used in the development of In-Ceram (Vident, Brea, CA).[10] This differed from glass-ceramics, where each reinforcing particle is completely surrounded by their glassy matrices. The second strategy was to eliminate the glassy matrix, either replacing it with resin or directly sintering crystals together without any intervening matrix.[11]

In-Ceram was introduced as an alternative to conventional metal-ceramic restorations in 1988, and it has met with great clinical success.[12-14] The In-Ceram core can be fabricated by slip casting a meshwork followed by controlled sintering (Fig 1). The carefully controlled sintering joins all the reinforcing components together without shrinkage or distortion of the core. Alternatively, cores can be formed by milling from a presintered block (Figs 2a and 2b). The open spaces within the sintered core meshwork are then infiltrated with a low-viscosity lanthanum glass at a high temperature (Fig 3). Both alumina and spinel (an oxide of magnesium and aluminum) have been used to form the reinforcing skeletal core meshworks. These materials are 3 to 4 times stronger than prior dental ceramics.[6,7,15]

Different core meshwork materials result in different properties. The alumina cores are slightly stronger but less translucent than the spinel cores. Thus, the alumina cores are recommended for anterior and posterior crowns, and anterior fixed partial dentures, whereas the spinel cores are limited to anterior crowns. To achieve still greater strength, a new core material was introduced in 1999. Zirconia, an extremely strong metal oxide, has been included in the new stronger material. This new material, In-Ceram Zirconia, is recommended for use in posterior crowns and posterior fixed partial dentures. As in the conventional In-Ceram technique, it can be slip cast or milled from presintered blocks, and is then glass infiltrated.

This paper describes In-Ceram Zirconia, its composition and properties, as well as laboratory and clinical techniques for crowns, fixed partial dentures, and custom implant abutments.

Physical Properties of the Zirconia Core Material

The original alumina In-Ceram slip cast core material consisted of 99.9% alumina that was sintered at 1100°C and then glass infiltrated with a special lanthanum glass. The resultant interpenetrating-phase composite ceramic contained 85% alumina and only 15% glass. This interpenetrating-phase composite consists of two separate intertwining phases, alumina and glass, that extend throughout the body of the material.

After years of research it was found that the addition of 35% partially stabilized zirconia greatly enhanced the mechanical properties. Flexural strength, fracture toughness, and fatigue resistance were all improved.[16,17] Reported flexural strength values of this new zirconia-containing material range from over 600 to 800 MPa.[16–18] With all things being equal, it is better to have an inherently stronger material than a weaker one. Fracture toughness is an important measure of the resistance to crack growth in brittle ceramic materials. Ceramics tend to fail by growth of small imperceptible flaws into large catastrophic cracks. In-Ceram Zirconia has a reported fracture toughness of 6 and 8 $\text{MPa}\cdot\text{m}^{1/2}$.[16] This is substantially higher than reported for other dental ceramics, and is approximately twice that reported for Empress 2.

The improved physical properties can partially be attributed to a process called phase transformation toughening.[19] Partially stabilized zirconia exists in a tetragonal crystal configuration. When an external stress is applied to the tetragonal zirconia, it can undergo a phase transformation to a different monoclinic crystal configuration. The monoclinic crystal is 3% to 5% larger than the tetragonal crystal it replaced. This phase transformation increases local compressive stresses, which increase the resistance to crack propagation. Furthermore, grinding the surface of a zirconia-containing ceramic tends to produce a protective compressive surface layer.

Laboratory Procedures

The master dies are first duplicated after die spacing with a special plaster. For three-unit fixed partial dentures, the refractory dies are glued to an alumina block prior to sectioning. The dies are then sectioned maintaining the correct spatial relationship between the FPD abutments (Figs 4a and 4b).

This new zirconia material can be slip cast as in the conventional In-Ceram technique. The zirconia/alumina powder is mixed with deionized water and a dispersing agent. The resulting slurry is termed a "slip." A slip is defined as a suspension of fine, insoluble particles in a liquid. The slip is then built up with a brush on the special porous gypsum dies. The slip material is slightly overbuilt and allowed to dry (Fig 5). It is absolutely critical not to trap air between the layers or to allow a layer to dry before completing the buildup of the zirconia material; this will create porosity or an "onion skin"-layered effect in the final coping, which greatly weakens it. The porous die removes water from the slurry by capillary action. As they dry, the slurry particles get packed into a denser network. The dense, dried slurry is then carved to the general shape of a coping or FPD

Fig 4a Special plaster is poured into duplicated impression of prepared fixed partial denture preparations.

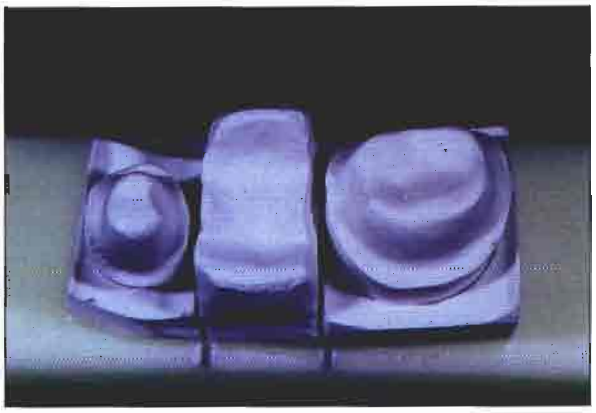


Fig 4b Special plaster pour, which is then glued to an alumina block and sectioned.

Fig 5 Buildup of the alimunina/zirconia slip for a three-unit posterior fixed partial denture.

Fig 6 Dried slip after it has been carved to the margins of the special plaster, preferably under a microscope.

framework, but still greater in contour than the desired final result (Fig 6). The most critical area to finish is the marginal area, which should be completed under a microscope. The zirconia/alumina framework is then placed in a special furnace (Inceramat, Vita, Bad Säckingen, Germany) and fired according to the manufacturer's instructions. During the firing cycle, water is driven off the gypsum die and it shrinks away from the coping/framework. The copings or frameworks can now be fitted back to the master dies and final contouring can be accomplished using diamond burs (Fig 7). The coping/framework looks and feels like blackboard chalk at this point; it is also very weak, so great care must be taken in its contouring.

Next, a special infiltration glass, corresponding to the patient's tooth shade, is applied to the coping/framework. This special glass is then infiltrated into the coping during a second firing in the Inceramat or a porcelain furnace (Fig 8). As the glass melts, it is drawn into the interstitial spaces between the zirconia/alumina grains by capillary action. The infiltration process can be manipulated by the differential use of vacuum during the firing cycle to adjust the translucency of the final core or framework . Once infiltrated, any excess infiltration glass is easily removed by air abrasion.

Alternatively, copings/frameworks can be milled from presintered blocks. The introduction of milling and CAD/CAM technology to

Fig 7 Partially sintered framework is contoured with diamond burs and is ready for glass infiltration.

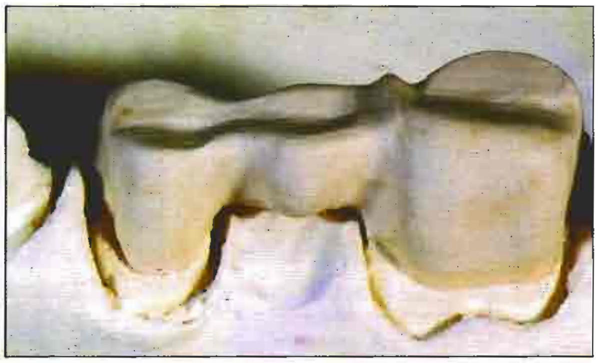


Fig 8 Finished framework after glass infiltration, ready for porcelain application. The distal marginal ridge of the pontic is made of core material for increased strength.

dentistry has facilitated the development and application of superior dental ceramics. Tightly controlled industrial ceramic processing produces increased microstructural uniformity, higher density, lower porosity, and lesser residual stresses. Such improvements suggest that increased clinical predictability can be expected from machinable materials.[20] Machinable blocks are now made for two milling systems, the Cerec II (Sirona) CAD/CAM device, and the Celay copy milling system. The blocks are machined to the desired geometry and then glass infiltrated by the same technique as the slip-cast material. Preformed machinable ceramic cylinders for custom implant abutments have recently become available.

■ Zirconia Custom Implant Abutments

Esthetic single-tooth or multiple-tooth implant-supported restorations are particularly difficult to fabricate for the maxillary anterior region. Titanium and other oxidizable metals often cause a darkening, shadowing, or graying of the overlying soft tissue. This darkening can be avoided with the use of a root-colored ceramic abutment. The first ceramic abutment marketed for this purpose was the CerAdapt abutment (Nobel Biocare AB, Gothenburg, Sweden).[21] The CerAdapt abutment is made of solid sintered alumina that can be contoured to the desired shape. However, solid sintered alumina is difficult to grind and can be fractured during grinding. Partly sintered abutment blocks of In-Ceram Zirconia will soon be available for the use with standard hex head implants (Fig 9). The partly sintered material is easy to contour and finish with diamond burs (Fig 10). Once the custom contouring is completed, the abutment is infiltrated with the special glass to confer the final optical and strength properties (Fig 11).[22] The abutments can be tried in the mouth to verify contour and margin placement. Should additional contouring be necessary, the blue diamond impregnated wheel called Dialite (Brasseler, Savannah, GA) can be used. Alpha porcelain (Vita) can be fired directly to the abutment to create the final restoration, or a separate cementable crown can be fabricated to fit the custom abutment (Figs 12a and 12b). We prefer Spinell (Vita) for anterior all-ceramic crowns due to its excellent optical characteristics (Figs 13a and 13b).[4]

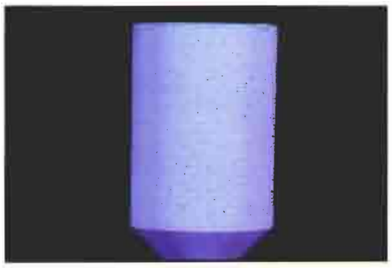


Fig 9 Presintered and uninfiltrated zirconia abutment for use with standard hex-head Brånemark-type implants.

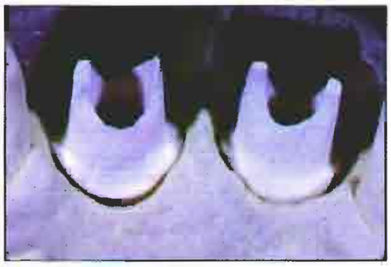
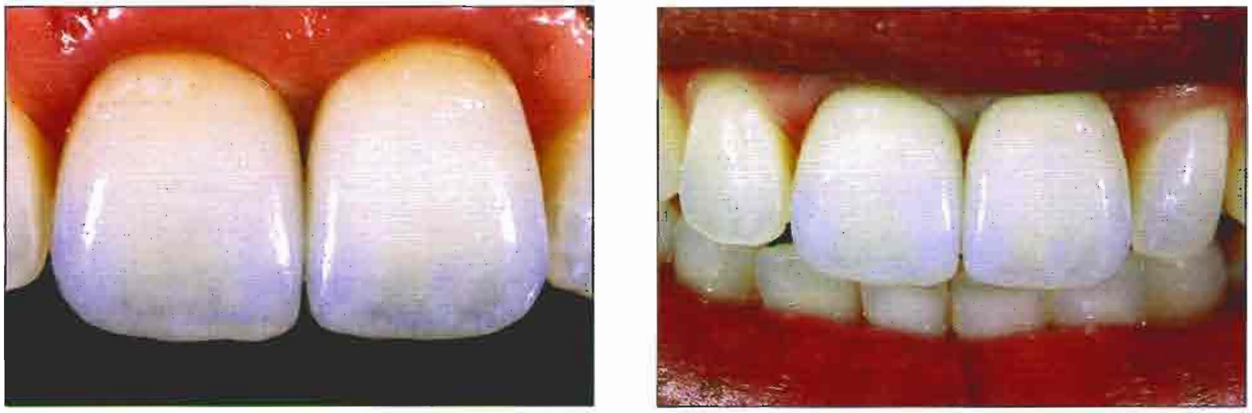


Fig 10 Contoured zirconia abutments ready for glass infiltration.

Fig 11 Glass-infiltrated zirconia abutments, ready for crown fabrication.



Figs 12a and 12b Finished Spinell crowns on custom In-Ceram Zirconia abutments.

Figs 13a and 13b Single Spinell crown on the maxillary left central incisor.

Treatment Planning

Single posterior crowns would appear to be the ideal indication for In-Ceram Zirconia due to its excellent strength characteristics. Accepted guidelines for preparation and cementation of In-Ceram Alumina crowns should be followed in addition to the comments below.[23,24] Three-unit posterior In-Ceram Zirconia FPDs should only be considered in situations where optimal framework dimensions can be obtained as described below. Evaluation of preoperative study casts can determine if adequate dimensions for the framework connector are possible (Fig 14). First molar replacement with an FPD is possible if all design parameters and preparation guidelines, including the placement of proximal boxes, are met. Posterior all-ceramic FPDs should only be considered in situations of metal allergy or with the full understanding of the patient that no long-term data exist to support their use and thus they are experimental.

Guidelines for Tooth Preparations

In-Ceram Zirconia crown and abutment preparations require a minimum of 1.0 mm of axial reduction. The author has found that 1.5 mm or more reduction is necessary in esthetic areas, ie, on the buccal aspects of preparations. A 360-degree shoulder preparation that is 1.0 mm thick is ideal. Thin or beveled margins cannot easily be reproduced in ceramic, and better marginal fidelity can be achieved with a shoulder preparation.[23] Occlusal reduction of 1.5 mm is the minimum amount necessary, with 2.0 mm being more ideal. As already stated, it is necessary to place a proximal box in abutment preparations adjacent to the edentulous space, to allow bulking of the framework at the axio-occlusal line angle. Internal line angles should be rounded; this minimizes stress concentration, which could lead to fracture. Sharp external line angles also concentrate stresses, as well as overthinning the core, which would weaken the prosthesis.

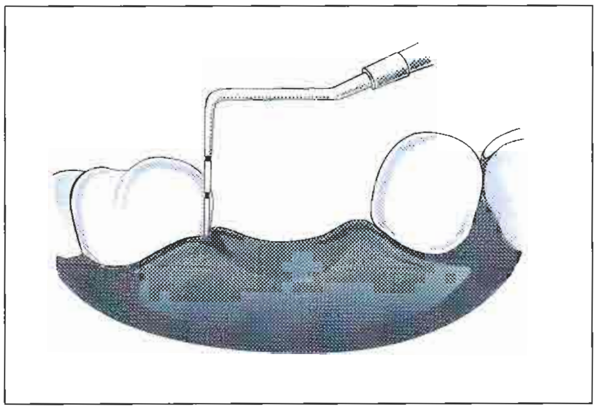


Fig 14 Diagram of preoperative cast using a perio-probe to determine if adequate space exists for proper framework dimensions.

After final preparation, accurate and detailed impressions are necessary to fabricate the restoration. Take One (Kerr, Orange, CA) or Imprint II (3M, St Paul, MN), a polyvinyl siloxane with excellent rheologic properties, is recommended; the material should have the ability to do multiple pours for dies.

Framework Design for In-Ceram Zirconia Crowns

According to McLean, ceramics with flexural strengths around 150 MPa are inadequate for use in molar crowns.[25] Flexural strengths from 300 to 600 MPa have been reported for In-Ceram Alumina, which has successfully been used for molar crowns.[4,13,14] In-Ceram Zirconia has a substantially higher flexural strength of 600 to 800 MPa and is recommended by the manufacturer for use in anterior and posterior single crowns as well as for selected three-unit posterior FPDs. The In-Ceram Zirconia core material is not used alone, but is veneered with a weaker porcelain to achieve the final esthetic result. Evaluation of the effects of veneering porcelain on the In-Ceram alumina demonstrated only a minimal drop in strength if the core thickness remained 1 mm thick.[26] When the core was thinned to 0.5 mm and then veneered with

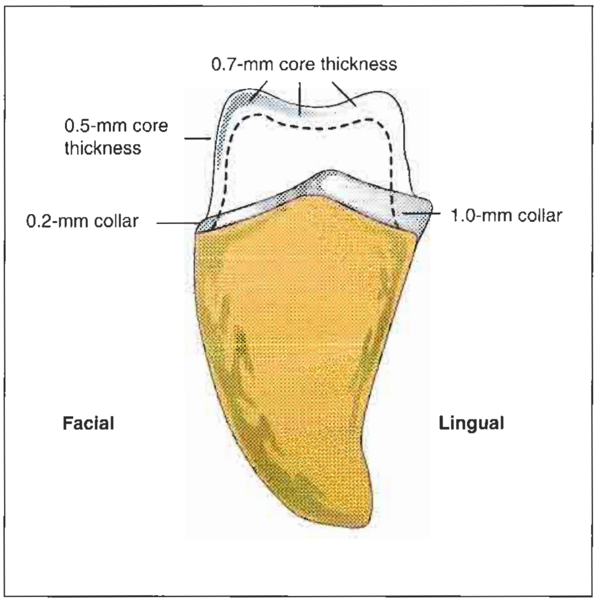


Fig 15 Diagram of proper framework design for posterior zirconia all-ceramic crowns.

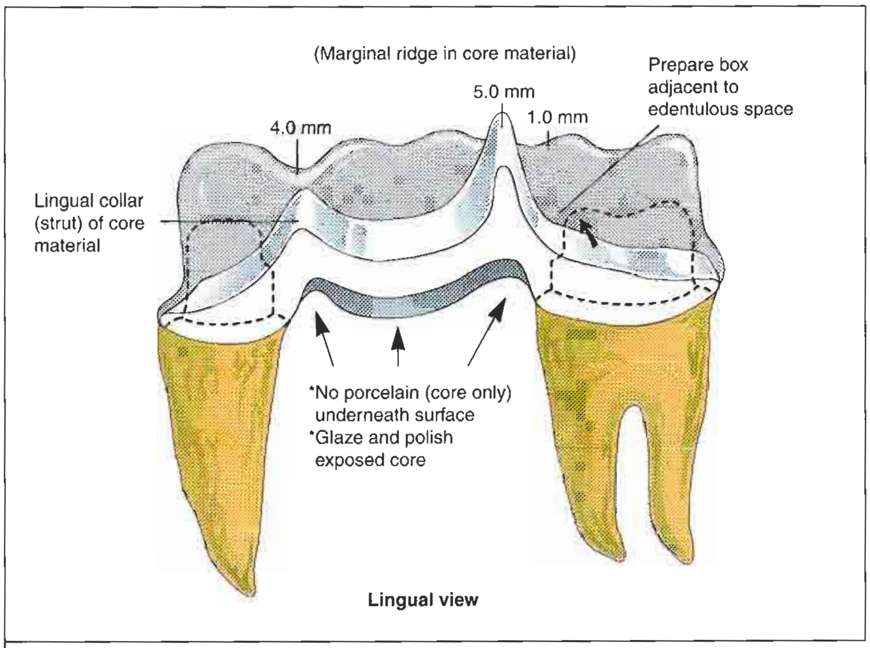
porcelain, flexural strength dropped dramatically.[26] Due to the high Alumina content of the In-Ceram Zirconia material, it can be theorized that a relative drop in strength can be anticipated with increasing thickness of veneering porcelain and decreasing thickness of core material. Thus, it is advisable that the thickness of the In-Ceram Zirconia core material be maximized as much as possible.

A review of failed In-Ceram Alumina single-crown restorations found no failures when a core thickness of 0.7 mm or greater was used.[4] All failures originated from occlusal line angles or internal flaws in the cores. With the slip-casting technique it is possible to trap air, creating porosity that could weaken the core. It is important that the technician and dentist inspect the inside surface of the core and reject any cores with visible porosities or flaws. None of the restorations milled from prefabricated alumina or spinel blocks have yet failed. The premanufactured blocks are more uniform and do not contain processing voids. This may lead to increased predictability of clinical performance.

According to the manufacturer, In-Ceram Zirconia cores can be thinned to 0.5 mm for crown copings. It may be advisable to thicken the core in areas of high stress. For posterior crowns, occlusal and palatal core thicknesses of 0.7 mm are suggested. Ideally, the coping should have a lingual and proximal collar for strength and to support the veneering porcelain. The collar should be 1 mm thick and 2 mm high (Fig 15). For anterior teeth, core dimensions could be trimmed to 0.3 mm on the facial aspects, as long as the interproximal, palatal, and incisal edge thickness remains at least 0.7 mm and there is a 1-mm-thick lingual collar. In-Ceram Zirconia can be used for anterior teeth, but it requires a thicker porcelain veneer and a porcelain labial margin to achieve optimal esthetics.

■ Framework Design for In-Ceram Zirconia Fixed Partial Dentures

Although In-Ceram Zirconia is recommended by its manufacturer for the fabrication of posterior three-unit FPDs, it is important to note that no published clinical data yet support the use of Zirconia or any other all-ceramic material for this purpose. Initial strength data and early clinical trials look promising, but no long-term conclusions can be drawn. Thus the practitioner is advised to be prudent in case selection for these new materials, and only use them where ideal framework dimensions can be obtained, and where they will not be exposed to excessive forces. Attention to framework design is more critical than for conventional metal-ceramic restorations. The connectors for the framework should be at least 4 mm long occlusal to gingival, and ideally 5 mm if a first molar is being replaced. Buccal to lingual connector thickness should be 4 mm in the molar region or 3 mm in the premolar region. The axio-occlusal line angle facing the pontic should be at least 1 mm thick. The occlusal and palatal axial surfaces should be at least 0.7 mm thick, and the facial axial surface should be at least 0.5 mm thick (Fig 16).



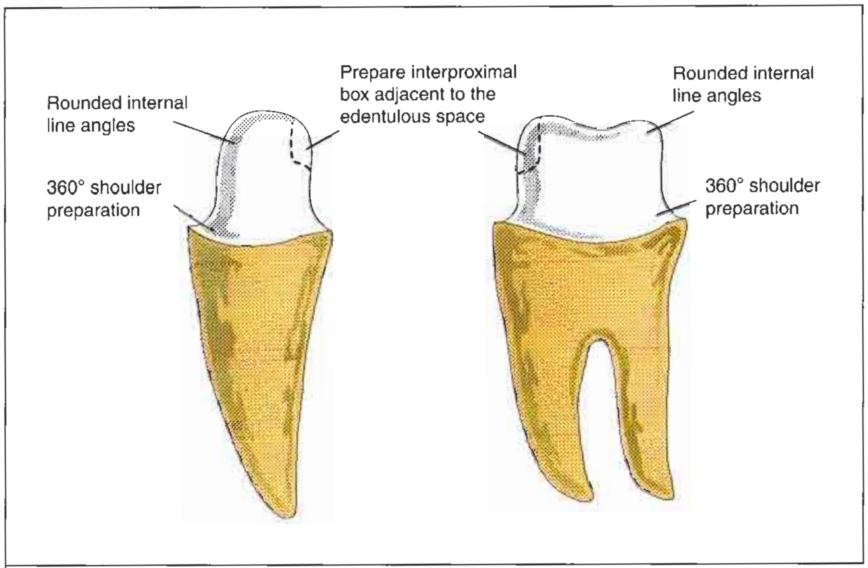
16

Fig 16 Diagram of proper framework design for zirconia posterior three-unit fixed partial dentures.

Against the manufacturer's instructions, we used In-Ceram Alumina for some posterior FPDs. Analysis of failed FPDs revealed some interesting findings. Failures originated in one of two places, through the distal connector or through the axio-occlusal line angle. These areas concentrate more stress and thus should be bulked up more in the framework design, even in the much stronger zirconia-based material. Therefore, the marginal ridge of the mesial aspect of the distal retainer and the entire thickness of the connector should be made of unveneered core material so as to maximize strength in this critical area (Fig 17). The other critical area to bulk up is the axio-occlusal line angle. Extra room for the thickened core can be accomplished by modifying the preparation to create more room in this area. We recommend preparing small boxes on both abutments adjacent to the pontic space to allow for greater framework thickness adjacent to the connectors as stated earlier (Fig 18).

Another concern with all-ceramic FPDs is design of the layering of the relatively weak veneering porcelain around the connectors. Analysis of layered beams of In-Ceram Alumina veneered with porcelain clearly showed that placing porcelain on the tensile, or tissue-facing, surface significantly weakened the structure.[27,28] This is also true for the Procera system (Nobel Biocare AB).[29] Layered beams leaving uncovered In-Ceram Alumina on the tensile surface and porcelain on the compressive surface were almost as strong as solid beams of In-Ceram. In-Ceram Zirconia is expected to behave the same way. Thus, no porcelain should be placed on the underneath tissue-facing or tensile surface of the connector area in the gingival embrasures (Fig 18). The lingual embrasures should not be covered with porcelain, as this space is necessary for core material to achieve proper framework dimensions. These exposed core areas should be glazed and polished after porcelain firings. Glazing and polishing In-Ceram Alumina has demonstrated a significant increase in flexural strength.[27] This effect is anticipated with the Zirconia material.

Mobile abutments should not be considered for In-Ceram Zirconia FPDs, as this will concentrate stress in the connector areas leading to premature failure. Unless these very specific requirements for posterior In-Ceram Zirconia FPDs can be met, a metal-ceramic restoration is preferred.



17

Fig 17 Diagram of proper preparations for abutments for a posterior fixed partial denture. Note the interproximal boxes placed adjacent to the edentulous space. These are not placed for retention/resistance, but rather to increase the thickness of the core material in this region.

Fig 18 Finished In-Ceram Zirconia fixed partial denture has no porcelain in the gingival embrasures. The exposed core has been glazed and polished. Note the porcelain labial margin on the facial aspect of the premolar.

■ Porcelain Application

Porcelain application procedures are the same as for In-Ceram Alumina. One occasional problem we experienced with In-Ceram Alumina was delamination of porcelain from the core. According to the manufacturer's instructions, the first porcelain application is fired at a relatively low temperature. This relatively low firing temperature may limit the wetting of the core by porcelain and reduce bonding. For metal-ceramics, a thin wash layer of opaque porcelain is fired at a high temperature to create a layer of glass that wets and bonds well. Although this step is not usually done with all-ceramic systems, we recommend placing a thin layer of opacious dentin porcelain over the whole In-Ceram framework and firing it to 1000°C in vacuum with a 1-minute hold in air to achieve good wetting and bonding. This creates a thin layer of glass that is well bonded to the zirconia core. The core is then lightly air abraded with aluminous oxide grit to break the glaze to facilitate further porcelain application.

In areas that are visible during speech and smiling it is best to plan for a porcelain butt margin by cutting back the core on the facial aspect. The facial surfaces of most maxillary premolars and some maxillary first molars are visible during a full smile. It is advisable to use a more translucent material as a porcelain margin for In-Ceram Zirconia FPDs (Fig 19) in these areas. Special porcelains called Luminaries (Vita) are used for the porcelain margin. Once the restoration is in place, the marginal area blends in with the existing tooth structure by the "chameleon effect."[31] The porcelain buildup is completed using the "Skeleton Buildup Technique," which is

Fig 19 Buccal margin of a posterior zirconia-core all-ceramic crown with a porcelain margin for better esthetics.

Fig 20 Cemented single In-Ceram Zirconia crowns with Alpha porcelain on the right premolars and first molar.

Fig 21 Cemented three-unit maxillary fixed partial denture replacing a second premolar.

19

20

21

fully described elsewhere.[32,33] The clinical cases in Figs 20 and 21 demonstrate final results attainable with the zirconia/alumina-based ceramic for posterior applications.

■ Cementation

Due to the high strength of In-Ceram Zirconia, conventional cements can be used. Glass-ionomer cements have been used with great clinical success in dentistry, and have been successfully used with In-Ceram Alumina.[4] Glass-ionomer cement is extremely sensitive to the powder-liquid ratio. Even small alterations affect its physical properties and clinical performance. Glass-ionomers are susceptible to early moisture attack, which requires exquisite saliva control until the cement is completely set. Pre-encapsulated versions are available (Applicap, ESPE, Norristown, PA); they eliminate the problems associated with attaining the proper powder-liquid ratio and are preferred to the hand-mixed versions. Clinical experience with zinc phosphate cement found a high incidence of microleakage and staining at the margins, as well as a slightly higher incidence of fracture, so it is not recommended. Polycarboxylate cements have poor physical properties, and their use is unsupported by published data.

Recently, there have been anecdotal reports about compomer cements causing cracking of all-ceramic crowns shortly after cementation.[34,35] These products contain large amounts of hydroxyethyl mechacrylate (HEMA), which expands on exposure to moisture. It is theorized that the expansion of HEMA causes sufficient stresses to cause cracking. In a laboratory study, all-ceramic crowns were fabricated and cemented with various compomer cements and stored in water.[34] Cements were also placed in capillary tubes and stored in water. Several of the crowns fractured after a few days stored in water, but exact percentages were not given. Of the capillary tubes filled with cement, 71% of the Advance (Caulk, Milford, DE) specimens fractured, 25% of the FUJI Plus (GC America, Chicago, IL) specimens fractured, and none of the Vitremer (3M, St Paul, MN) specimens fractured. That study also measured linear expansion of the compomer cements. The compomers expanded 5 times more than conventional cements or a conventional composite resin cement, Panavia 21 (J. Morita, Tustin, CA). Based on these data and many anecdotal reports of fracture, compomer cements should not be used for all-ceramic restorations. Although many dentin bonding agents contain HEMA, it is in small amounts in very thin layers, so expansion problems are negligible. Therefore, HEMA-containing dentin bonding agents can safely be used with In-Ceram.

The ability to acid etch and adhesively bond conventional porcelain has greatly increased its clinical predictability. Hydrofluoric acid dissolves the glassy matrix, leaving microscopic undercuts around leucite crystals. Low-viscosity resins are used; they fill these retentive areas to create a strong micromechanical bond. However, hydrofluoric acid etching and silane coating do not increase adhesion in In-Ceram because it contains much less glass than conventional porcelain.[36] Kern recently reported high bond strengths of In-Ceram Alumina to a new resin and with various surface treatments designed to increase the surface silica content In-Ceram.[37] We found that specific surface treatments and resin combinations in both In-Ceram Alumina and Spinell gave shear bond strengths equal to those of etched porcelain, although the long-term nature of the bond is not yet known.[30] The surface treatment protocol for adhesive luting of In-Ceram Alumina or Spinell is to air abrade the internal surface of the core with 50 µm aluminous oxide at 50 psi for 10 seconds. Any other surface treatment lowered the bond strength. As the composition and microstructure of In-Ceram Zirconia is similar to that of In-Ceram Alumina, it is expected that the same treatment protocol will be effective for In-Ceram Zirconia. Hydrofluoric acid or silane should not be used for surface treatment of In-Ceram because they both lowered bond strength. The only cement that exhibited high bond strength to In-Ceram was Panavia 21TC (J. Morita). A dentin bonding agent should be placed on the tooth to minimize the potential for postcementation sensitivity. Only mixed Panavia 21TC is placed in the crown. Once the crown is placed, excess cement is removed and Oxyguard II (J. Morita) is placed. Oxyguard II facilitates the set of the Panavia.

The main rationale for using translucent all-ceramic restorations is to match the translucency and value of the natural dentition. However, most conventional cements are relatively opaque and they can negatively affect the final optical result of the cemented restoration. Translucent resin cements are indicated if maximum translucency is needed when In-Ceram Zirconia is used for anterior restorations. The optical properties of Panavia 21TC and Variolink (Vividness, Amherst, NY) have been found to be ideal for use with In-Ceram Zirconia.

■ Summary and Conclusions

The new zirconia-based ceramic presented in this article has the potential to expand treatment options for posterior fixed partial dentures. Treatment planning any restorative material involves careful consideration of several important criteria, not the least of which are the mechanical requirements to withstand the oral stresses. We practitioners must become *dental engineers*. An engineer is a person who uses materials and forces to benefit people. Dental materials are continuously subjected to a myriad of physical forces and chemical insults. The requirements for posterior restorative materials and cements are much more stringent than for anterior restorations. Therefore, we must have a basic understanding of the structural elements of a material and its concomitant physical properties. With this knowledge and an idea of the forces it will be subjected to, we can better predict how it will perform.

Clinical studies have demonstrated good survival rates for most all-ceramic systems on anterior teeth. Poorer performance of these materials, even high leucite ceramics, in the more critical posterior areas can be predicted.[5,38] The mechanical properties of In-Ceram Zirconia are an important step forward in the quest for durable all-ceramic posterior crowns and three-unit posterior fixed partial dentures. As with any all-ceramic system, other factors, such as eliminating processing flaws and proper framework design, are critical. Millable versions of In-Ceram Zirconia have improved physical properties over slip-cast zirconia. This is due to the more homogeneous nature and increased density of the preprocessed blocks.

Specific requirements for tooth preparation are recommended. These include adequate reduction, shoulder margins, and the absence of sharp line angles. The placement of boxes in the proximal surfaces of abutments to allow greater bulk of core material in the connector areas is recommended.

For single crowns, copings must be at least 0.5 mm thick, or 0.7 mm thick in areas of high stress. In addition, gingival collars of core material should be used for reinforcement in less esthetically critical areas. For fixed partial dentures, framework design is critical. Connector design of 4 mm gingivo-occlusal height (or 5 mm for molar replacement) and 4 mm buccolingual width are critical. Porcelain should be not be placed in the gingival or lingual embrasure connector areas, and the exposed core material should be glazed and polished.

Acid etching and adhesive cementation of conventional porcelain and glassy high-leucite all-ceramic restorations is paramount for their long-term clinical success. However, In-Ceram Zirconia's high strength allows luting with some conventional cements. Pre-encapsulated glass-ionomer is the cement of choice for routine cementation. When high bond strengths are desired, aluminous oxide air abrasion and cementation with Panavia 21TC is recommended.

■ Acknowledgments

Dr McLaren personally performed all clinical and laboratory porcelain work. The authors would like to thank Ky Hale, CDT, for making the Zirconia copings featured in this article.

■ References

1. Kelly JR, Nishimura I, Campbell SD. Ceramics in dentistry: Historical roots and current perspectives. J Prosthet Dent 1996;75:18–32.
2. Anusavice KJ. Recent developments in restorative dental ceramics. J Am Dent Assoc 1993;124:71–84.
3. American Dental Association Survey Center. 1990 survery of dental restorations. In: Survey of Dental Services, 1990. Chicago: ADA Survey Center.
4. McLaren EA. All-ceramic alternatives to conventional metal-ceramic restorations. Compend Contin Educ Dent 1998;19:307–325.
5. Malament KA, Grossman DG. Bonded vs. non-bonded Dicor crowns: Four-year report [abstract 1720]. J Dent Res 1992;71:321.
6. Seghi RR, Daher T, Caputo A. Relative flexural strength of dental restorative ceramics. Dent Mater 1990;6:181–184.
7. Seghi RR, Sorensen JA. Relative flexural strength of six new ceramic materials. Int J Prosthodont 1995;8: 239–246.
8. Jones DS. The strength and strengthening mechanisms of dental ceramics. In: McLean JW, ed. Dental Ceramics: Proceedings of the First International Symposium on Ceramics. Chicago: Quintessence, 1983.
9. Rosenstiel SF, Gupta PK, Van Der Sluys RA, Zimmerman MH. Strength of a dental glass-ceramic after surface coating. Dent Mater 1993;9:274–279.
10. Sadoun M. All-ceramic bridges with slip casting technique. Presented at the 7th International Symposium on Ceramics, Paris, September 1988.
11. Anderson M, Oden A. A new all-ceramic crown: A densely-sintered, high-purity alumina coping with porcelain. Acta Odontol Scand 1993;51:59–64.
12. Claus H. Vita In-Ceram: A new system for producing alumina oxide crown and bridge substructures [in German]. Quintessenz Zahntech 1990;16:35–46.
13. Probster L. Survival rate of In-Ceram restorations. Int J Prosthodont 1993;6:259–263.
14. Scotti R, Catapano S, D'Elia A. A clinical evaluation of In-Ceram Crowns. Int J Prosthodont 1995;8:320–323.
15. Giordano R, Pelletier L, Campbell S, Pober R. Flexural stength of alumina and glass components of In-Ceram. J Dent Res 1992;71:253.
16. Vita Zirconia product report, 1999.
17. Sorensen JA, Mito WT, Chamberlain TH. Core ceramic flexural strength from water storage and reduced thickness [abstract 906]. J Dent Res 1999;78:219.
18. Giordano RA. Dental ceramic restorative systems. Compend Contin Educ Dent 1996;17:779–794.
19. Lawn B. Fracture of Brittle Solids, ed 2. Cambridge, England: Cambridge University Press, 1993:221–230.

20. Rinke S, Huls A, Jahn L. Marginal accuracy and fracture strength of conventional and copy-milled all-ceramic crowns. Int J Prosthodont 1995;8:303–310.
21. Prestipino V, Ingber A. Elsthetic high-strength implant abutments. Part I. J Esthet Dent 1993;5:29–35.
22. Sadoun M, Perelmuter S. Alumina-zirconia machinable abutments for implant-supported single-tooth anterior crowns. Pract Periodontics Aesthet Dent 1996;9: 1047–1053.
23. Sorensen JA, Torres TJ, Kang SK, et al. Marginal fidelity of ceramic crowns with different margin designs [abstract 1365]. J Dent Res 1990;69:279.
24. Probster L, Diehl J. Slip casting alumina ceramics for crown and bridge restorations. Quintessence Int 1992;23: 25–31.
25. McLean JW, Kedge MI. High-strength ceramics. Quintessence Int 1987;18:97–104.
26. McLean JW. New dental ceramics and esthetics. J Esthet Dent 1995;7:141–149.
27. McLaren EA, Sorensen JA. Flexural strength of ceramic materials with different surface treatments [abstract 3031]. J Dent Res 1997;76:392.
28. White SN, Caputo AA, Vidjak FM, Seghi RR. Moduli of rupture of layered dental ceramics. Dent Mater 1994;10: 52–58.
29. Wagner WC, Chu TM. Apparent flexural strength of porcelain veneered all-ceramic core material [abstract 2129]. J Dent Res 1996;75:284.
30. McLaren EA, Sorensen JA. Composite cement to In-Ceram Spinell shear bond strength [abstract 170]. J Dent Res 1995;74:422.
31. Materdomini D, Friedman MJ. The contact lens effect: Enhancing porcelain veneer esthetics. J Esthet Dent 1995;7:99–103.
32. McLaren EA. The Skeleton Buildup Technique: A systematic approach to the three-dimensional control of shade and shape. Pract Periodontics Aesthet Dent 1998;10: 587–597.
33. McLaren EA. The 3D-Master shade matching system and the Skeleton Buildup Technique: Science meets art and intuition. Quintessence Dent Technol 1999;22:55–68.
34. Resin-reinforced glass ionomer cements: All-ceramic crown fracture. CRA Newsl 1996;20(Nov):3.
35. Miller MB. Resin ionomer luting cements. Reality Now Newsl 1995;68(July):1–2.
36. Kraivixien-Vongphantuset R, Pietrobon N, Nathanson D. Bond strength of resin cement to In-Ceram core material [abstract]. J Dent Res 1992;71:533.
37. Kern M, Thompson VP. Bonding to glass infiltrated alumina ceramic: Adhesive methods and their durability. J Prosthet Dent 1995;73:240–249.
38. Hankinson JA, Cappetta EG. Five years' clinical experience with a leucite-reinforced porcelain crown system. Int J Periodontics Resorative Dent 1994;14:139–153.

Highlights

by Avishai Sadan, DMD and
Thomas J. Salinas, DDS

The Advantages of a Wider Perspective

Ed McLaren is one of the few restorative dentists who is also a skilled ceramist. In addition, he is involved in research related to all-ceramic clinical applications. All his clinical cases are completed by him as the clinician and technician, and the rationale for his treatment plan is based on data obtained from scientifically valid research. This rare combination of prosthodontist/ceramist/researcher displays not only unique clinical skills, but also a thorough understanding of the various aspects of his field of specialty. Since it takes some time to master each of the aforementioned fields (clinic/laboratory/research), this combination is unlikely to become a common occurrence. Today's fast-paced field of dentistry results in more clinicians and technicians strongly emphasizing, specializing, and practicing one focus of dentistry.

Although we may not all be able to practice in multiple capacities as a clinician/technician/researcher, we should understand the benefits of expanding our knowledge in fields that are not directly related to the procedures we practice. Clinicians attending continuing education courses intended for technicians and vice versa will soon find that extra knowledge provides a broader perspective from which they can better treatment plan and practice dentistry and/or dental technology.


Ed McLaren