Contemporary materials and technologies for all-ceramic fixed partial dentures: A review of the literature

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High-strength all-ceramic systems for fixed partial dentures (FPDs) are available for replacing a missing tooth. New core/framework materials have been developed and have evolved in the last decade. With the advancement of CAD/CAM technology, various fabrication techniques have been developed for fabricating improved, consistent, and predictable restorations in terms of strength, marginal fit, and esthetics and for managing core/framework materials that could not otherwise be managed. This article reviews the evolution and development of materials and technologies for all-ceramic FPDs through data published between 1966 and 2004 in the English language. Peer-reviewed articles were identified through a MEDLINE search and a hand search of relevant textbooks and annual publications. The available information suggests that clinical data on the success of these restorations are limited, and that the results of long-term clinical studies are critical to the assessment of these restorations to provide more specific guidelines for usage. (J Prosthet Dent 2004;92:557-62.)

The success of all-ceramic crowns and patient demand for metal-free, tooth-colored restorations has led to the development and introduction of restorative systems for all-ceramic fixed partial dentures (FPDs). These systems continue to be evaluated in clinical studies for their predictability and long-term success. However, the idea of providing patients with this treatment modality is not innovative. In 1967, McLean introduced the idea of fabricating a high-alumina ceramic for the fabrication of FPD pontic structures.[1] In 1982, McLean introduced the platinum-bonded alumina FPD to reduce the problem of fracture through the connector area while eliminating the traditional cast-metal framework.[2] However, this restorative option demonstrated a high rate of failure at the connector sites. Since then, developments in dental ceramics have led to the introduction of new high-strength ceramic core materials for all-ceramic FPDs.

The clinical fracture resistance of FPDs is related to the size, shape, and position of the connectors and to the span of the pontic. The basis for the proper design of the connectors and the pontic is the law of beams: deflection of a beam increases as the cube of its length, it is inversely proportional to its width, and it is inversely proportional to the cube of its height.[3] A 3-point bending test is one of the most commonly used tests to determine the modulus of rupture or the transverse flexural strength of a rectangular beam made of a brittle material.[4,5] When occlusal forces are applied directly through the long axis of an all-ceramic FPD at the midspan (pontic), compressive stresses will develop at the occlusal aspect of the connector at the marginal ridge, and tensile stresses will develop at the gingival surface of the connector.[6] These tensile stresses contribute to the propagation of microcracks located at the gingival surface of the connector through the core material in an occlusal direction, and may eventually result in fracture. Several high-strength all-ceramic core materials have been developed for fabricating all-ceramic FPDs, with several types of technologies applied for their fabrication (Table I). The purpose of this article was to review the evolution and development of the core materials and technologies used for all-ceramic FPDs by discussing the different core materials and their properties, the in vitro and in vivo data available, the design and manufacturing technologies, the criteria for patient selection, and the limitations of such restorations. Peer-reviewed articles published in English between 1966 and 2004 were identified through a MEDLINE search and a hand search of relevant textbooks and annual publications.

LITHIUM DISILICATE

The Empress II system uses a lithium-disilicate glass core material. The framework is fabricated with either the lost-wax and heat-pressure technique or is milled out of prefabricated blanks. Various types of tests measuring the flexural strength of the framework material demonstrated a range of 300-400 MPa.[7] Fracture toughness describes the resistance of brittle materials to the catastrophic propagation of flaws under an applied stress. For the lithium disilicate core material, the fracture toughness (K_{IC}) ranges between 2.8 and 3.5 $MPa/m^{½}$.[7,8] While these glass-containing materials

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Table I. Features of all-ceramic systems for FPDs

System (manufacturer)	Core material	Flexural strength (MPa)	Fracture toughness K_{IC}(MPa/m$^{1/2}$)	Connector surface area
Empress II[7-9] (Ivoclar North America, Amherst, NY)	Lithium disilicate	300-400	2.8-3.5	12-20 mm^2
InCeram Alumina[10-16] (Vita Zahnfabrick, Bad Sackingen, Germany)	Glass-infiltrated alumina	236-600	3.1-4.61	12 mm^2
In-Ceram Zirconia[13,15,16,23] (Vita Zahnfabrick, Bad Sackingen, Germany)	Glass-infiltrated alumina with 35% partially stabilized zirconia	421-800	6-8	12-20 mm^2
Procera AllCeram Bridges[16,18-22] (Nobel Biocare, Goteborg, Sweden)	Densely sintered high-purity alumina	487-699	4.48-6	6 mm^2
Cercon[21,30] (Dentsply Ceramco, Burlington, NJ)	Y-TZP	900-1200	9-10	7-11 mm^2
DCS-Precident DC-Zirkon[21,31] (Dentsply Austenal, York, Pa)	Y-TZP	900-1200	9-10	16 mm^2
Lava[21,32] (3M ESPE, St. Paul, Minn)	Y-TZP	900-1200	9-10	9 mm^2

allow the fabrication of relatively translucent restorations, it is recommended that these restorations be etched and adhesively luted to enhance their strength and longevity.[9] The system is confined to fabricating 3-unit FPDs that replace a missing tooth anterior to the second premolar. The minimal critical dimensions for the connectors are 4 to 5 mm occlusogingivally and 3 to 4 mm buccolingually.[9]

GLASS-INFILTRATED ALUMINA

The In-Ceram Alumina system, which uses high-temperature sintered-alumina glass-infiltrated copings for all-ceramic crowns, was the first restorative system introduced for the fabrication of 3-unit anterior FPDs.[10,11] To fabricate the framework, the ceramist can use either the slip-casting technique or milling out of prefabricated partially sintered blanks. The flexural strength of the framework material ranges from 236 to 600 MPa,[12-15] and the fracture toughness ranges between 3.1 and 4.61 MPa/m^{½}.[16,17] With this system, the minimal critical dimensions for the connectors are 4 mm occlusogingivally and 3 mm buccolingually.[11]

DENSELY SINTERED HIGH-PURITY ALUMINUM-OXIDE

The Procera AllCeram system uses a densely sintered high-purity aluminum-oxide as the core material.[18] Various types of tests measuring the flexural strength of the framework material demonstrated a range from 487 to 699 MPa.[16,19,20] For this core material the fracture toughness ranges between 4.48 and 6 MPa/m^{½}.[16,21] The recommended connector height is 3 mm, and the recommended connector width is 2 mm.[22]

GLASS-INFILTRATED ALUMINA WITH 35% PARTIALLY STABILIZED ZIRCONIA

Finally, the In-Ceram Zirconia system combines the use of glass-infiltrated alumina with 35% partially stabilized zirconia for the core material. As with the In-Ceram Alumina system, the ceramist may use the slip-casting technique or milling out of prefabricated partially sintered blanks to fabricate the framework. The results of various types of tests measuring the flexural strength of the core material have been reported to range from 421 to 800 MPa.[13,15,16,23] For the glass-infiltrated alumina core material the fracture toughness ranges between 6 and 8 MPa/m^{½}.[23] For such a restoration, the recommended minimal critical dimensions for the connectors are 4 to 5 mm occlusogingivally and 3 to 4 mm buccolingually.[23] A recent study demonstrated that, in terms of translucency, the In-Ceram Zirconia core is as opaque as a metal-alloy core.[24] Therefore, In-Ceram Zirconia is not recommended for fabricating anterior all-ceramic FPDs, where the translucency of the all-ceramic core materials is a major factor in enhancing an esthetic result. [11]

YTTRIUM TETRAGONAL ZIRCONIA POLYCRYSTALS (Y-TZP) BASED

The most recent core materials for all-ceramic FPDs are the yttrium tetragonal zirconia polycrystals (Y-TZP)–based materials. Y-TZP–based materials were initially introduced for biomedical use in orthopedics for total hip replacement and were successful because of the material's excellent mechanical properties and biocompatibility.[25] It was not until the early 1990s that the use of Y-TZP expanded into dentistry for endodontic dowels and implant abutments.[26-29] This material is currently being evaluated as an alternative core material for complete-coverage restorations such as all-ceramic crowns and all-ceramic FPDs.[30-32]

Yttrium oxide is a stabilizing oxide added to pure zirconia to stabilize it at room temperature and to generate a multiphase material known as partially stabilized zirconia.[33] The high initial strength and fracture toughness of Y-TZP result from the physical property of partially stabilized zirconia.[33] Tensile stresses acting at the crack tip induce a transformation of the metastable tetragonal zirconium oxide form into the monoclinic form. This transformation is associated with a local increase of 3% to 5% in volume. This increase in volume results in localized compressive stresses being generated around and at the tip of the crack which counteract the external tensile stresses acting on the fracture tip.[33] This physical property is known as transformation toughening.[33]

The long-term stability of ceramics is closely related to subcritical crack propagation and stress corrosion caused by water in the saliva reacting with the glass, resulting in decomposition of the glass structure and increased crack propagation in glass-containing systems.[34] However, Y-TZP cores are glass free, and because they have a polycrystalline microstructure they do not exhibit this phenomenon.[35] Therefore, long-term stability of Y-TZP cores may be enhanced. In vitro studies of Y-TZP specimens demonstrated a flexural strength of 900 to 1200 MPa.[21] Y-TZP-based materials have demonstrated a fracture toughness of 9-10 MPa/$m^{1/2}$, which is almost double the value demonstrated by alumina-based materials, and almost 3 times the value demonstrated by lithium disilicate–based materials.[21] An in vitro study evaluating Y-TZP FPDs under static load demonstrated fracture resistance of more than 2000 N.[36]

IN VITRO DATA

Campbell and Sozio[37] found, in an in vitro study evaluating statically loaded all-ceramic and metal-ceramic FPDs, that ceramic FPDs developed vertical cracks in the connector region prior to failing, whereas the metal-ceramic control group developed cracks at the intaglio surface of the pontic prior to failing. Kelly et al[6] demonstrated in both in vitro and in vivo studies that the exclusive mode of failure in all-ceramic FPDs was a fracture of the connectors. These findings were further exhibited in several clinical studies evaluating all-ceramic FPDs.[38-42] Oh et al[43] demonstrated in a finite element analysis and a fractographic analysis that connector fracture was initiated at the gingival embrasure, and that a larger radius of curvature at the gingival embrasure will reduce the concentration of tensile stresses, thus affecting the fracture resistance of the FPD. Oh and Anusavice[44] demonstrated the same results in an in vitro study and concluded that sharp occlusal embrasures will not affect the fracture resistance of the FPD.

Thus, the primary cause of failure reported for all-ceramic FPDs differs from those reported for the metal-ceramic FPDs. To prevent such failures, the connectors of all-ceramic FPDs must have sufficient height and width. The strength, and therefore, the minimal critical dimensions of these connectors, are exclusively dependent on the type of ceramic material used for the core material.[45]

To ensure long-term success of metal-ceramic FPDs, the minimal critical dimensions recommended for the connectors are an occlusogingival height of 2.5 mm and a buccolingual width of 2.5 mm, which provide for a connector surface area of 6.25 mm^2.[46,47] These dimensions may be achieved both in the anterior and in the posterior segments. However, this is not the case for all-ceramic FPDs. Owing to the primary mode of failure and the brittleness of ceramics, the required connector dimensions for all-ceramic FPDs are larger than those recommended for metal-ceramic FPDs. This may be a major contributing factor in restricting the versatility of their use. Therefore, appropriate diagnosis, patient selection, and conception of the requirements of proper ceramic framework design are all crucial for the success of these restorations. As previously mentioned, the lack of required space for desired connector dimensions may contraindicate the fabrication of an all-ceramic FPD.[48]

IN VIVO DATA

In a recent clinical retrospective study evaluating 515 metal-ceramic FPDs, Walton calculated that the cumulative survival rate of metal-ceramic FPDs was 96% for 5 years, 87% for 10 years, and 85% for 15 years of service.[49] This cumulative survival rate was not related to the number of units restored by an FPD. Of the evaluated metal-ceramic FPDs, 299 were 3-unit metal-ceramic FPDs. In light of these current findings demonstrating the expected survival rate of the current standard of care, all-ceramic FPDs should demonstrate at least a similar survival rate in clinical studies to be considered a predictable restorative alternative. Walton also reported that modes of failure for metal-ceramic FPDs included tooth fracture, 38%; periodontal breakdown, 27%; loss of retention, 13%; and caries, 11%.[50] An earlier study showed that the primary cause of failure was dental caries (38%). Other modes of failure included delamination of the veneering porcelain, cement dissolution, defective margins, abutment fracture, dowel and core/root fracture, periodontal disease/abutment mobility, and periapical lesion resulting from pulpal involvment.[51]

The scientific clinical data available regarding the success of some of the all-ceramic systems for FPDs is limited in terms of the follow-up period because these restorations are relatively new.[52] In addition, the survival

Table II. Clinical success of all-ceramic FPDs

System	Number of FPDs	Follow-up, years	Success, %
In-Ceram Alumina[38]	61	3	88.5
In-Ceram Alumina[39]	20	5	90
In-Ceram Alumina[40]	36	5	88
In-Ceram Zirconia[41]	18	3	94.4
Empress II[42]	30	2	93

of these restorations over a relatively short recall period is relatively low as compared to the metal-ceramic standard (Table II). As previously mentioned, the almost exclusive mode of failure of these restorations was a fracture at the connector through the core material.[38-42]

Y-TZP–BASED RESTORATIONS

The use of all-ceramic restorations will increase the depth of translucency and light transmission across the entire restoration.[53] However, some of the zirconia-based systems (Cercon, DCS-Precident) utilize a white-colored core, which may limit their indications from an esthetic standpoint. Another system (Lava) uses a Y-TZP core that is relatively translucent and, at the same time, may mask underlying discolored abutments. Moreover, it can be colored in 1 of 7 shades, corresponding to the Vita-Lumin shade guide.[48] This allows the development of the shade of the restoration from its intaglio surface to the outer aspect of the veneering porcelain.[48] The ability to control the shade of the core may also eliminate the need to veneer the lingual and gingival aspects of the connectors in those situations where the interocclusal-distance is limited and the required connector dimensions are minimally achieved. In addition, the palatal aspect of anterior crowns and FPDs may be fabricated of the core material exclusively in situations of extensive vertical overlap and lack of space for lingual veneering porcelain.[48]

Clinicians may place the finish line of a tooth preparation either at the free gingival margin or slightly below it (0.5 mm) without compromising the esthetic result. This, in turn, reduces the possibility of iatrogenic periodontal disease. Moreover, the ability to place the finish line as previously described facilitates the making of an accurate impression. Ceramic materials in general are good insulators. All-ceramic systems have reduced thermal conductivity, resulting in less thermal sensitivity and potential pulpal irritation.[52]

A small percentage of the population is hypersensitive to dental alloys containing both noble and base metals, such as palladium and nickel. Metal-free ceramic systems eliminate this problem.[54-58] The biocompatibility of Y-TZP was evaluated in both in vitro and in vivo studies with no reported local or systemic adverse effects from the material.[59-62] The findings of 2 recent studies also demonstrated that fewer bacteria accumulated around Y-TZP than titanium in terms of number and presence of pathogens such as rods.[63,64]

Y-TZP–based cores present with a metal-like radiopacity that enhances radiographic evaluation of the restoration.[48] As a result of their mechanical and physical properties, Y-TZP–based FPD frameworks require a relatively small connector area compared to other all-ceramic core materials, such as glass-infiltrated alumina, glass-infiltrated alumina with 35% zirconia, and lithium disilicate, ranging between 7 and 16 mm^2 (Table I).[30-32] In addition, with Y-TZP–based materials, adhesive cementation may be used but is not mandatory, and traditional luting agents, including glass-ionomer cements, resin-modifed glass ionomer cements, and composite-resin luting agents, may be used.[30-32] To date, the long-term clinical data on the success of Y-TZP–based FPDs is not available because they are relatively new.

Design and manufacture of Y-TZP–based FPD frameworks

A Y-TZP–based FPD framework may be designed using either conventional waxing techniques or computer-assisted design (CAD). CAD software may allow technicians to custom-design an FPD framework while combining traditional concepts of design with material-derived requirements. Several Y-TZP–based restorative systems for crowns and FPDs have been described in the literature. The Cercon system requires conventional waxing techniques for designing the Y-TZP–based infrastructure. The DCS-Precident and Lava systems each use a different type of CAD technology with different features and design options.[30-32] Once the design of the framework is completed, the data is transferred to a milling unit for fabricating the framework. The data is either transferred from the CAD unit to the computer-assisted manufacturing (CAM) unit, or a conventional wax-pattern is scanned as it is with the Cercon system. The Cercon and Lava systems use partially sintered Y-TZP–based blanks for milling the infrastructures, whereas the DC-Zirkon infrastructures are milled from fully sintered Y-TZP–based blanks by the DCS-Precident system. With a partially sintered milled framework, the size has been increased to compensate for prospective shrinkage (20%-25%) that occurs during final sintering.[30,32] The milling process is faster and the wear and tear of hardware is less than the milling from a fully sintered blank.[30-32] The proponents of partially sintered frameworks claim that microcracks may be introduced to the framework during the milling procedure of a fully sintered blank,[65] whereas the proponents of milling of a fully sintered blank claim that because no shrinkage is involved in the process the marginal fit is superior.[31]

PATIENT SELECTION AND LIMITATIONS

As part of the diagnosis and decision-making process in selecting the appropriate treatment option for an individual patient, the edentulous space must be evaluated in terms of the prospective abutment height and interocclusal distance. To facilitate patient selection for all-ceramic FPDs, the clinician must confirm adequate prospective connector height for the framework material and veneering ceramics prior to determining the restoration of choice. A 4-mm clinical measurement with periodontal probe from interproximal papilla to the marginal ridge of the prospective abutment for posterior FPDs, or to the incisal embrasure for anterior FPDs, indicates adequate connector height for most contemporary all-ceramic systems. At times, the available space for the connector may be restricted owing to reduced interocclusal distance, which may make it difficult to achieve the required connector dimensions without compromising the biologic demands of open embrasures needed for facilitating plaque control and adequate oral hygiene maintenance.[48]

The concentration of heavy stresses in the connector area increases the risk of catastrophic fracture. Therefore, it is mandatory to evaluate prospective abutments in terms of their periodontal health with emphasis on abutment mobility. Prospective abutments exhibiting increased mobility should not be used as a foundation for all-ceramic FPDs. The use of all-ceramic FPDs with a cantilever design is questionable because of the possibility of developing heavy stress at the connector as the pontic acts as a lever that is depressed under occlusal forces. Finally, heavy bruxers who exhibit severe parafunctional activity that cannot be controlled may not be candidates for all-ceramic FPDs. With all-ceramic systems for FPDs, should the framework not fit precisely, a new definitive impression must be made, because the framework cannot be sectioned and joined as with metal-ceramic FPDs.

SUMMARY

New high-strength core/framework materials have been developed for all-ceramic FPDs. However, most of these systems are limited with respect to replacement of the anterior and premolar teeth, require large connector dimensions, and may require the use of more technique-sensitive clinical procedures such as adhesive cementation. The most contemporary systems use Y-TZP as the core material and may be an alternative treatment modality for replacing a missing tooth both in the anterior and in the posterior segments. In addition, such systems may prove to be simple to handle and less technique-sensitive from a clinical standpoint, while providing patients with esthetic and functional restorations. Currently, clinical data on the success of these restorations are limited. Long-term results of clinical studies are critical to the assessment of long-term success and for the establishment of more specific guidelines for their use.

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