

Current status of zirconia-based fixed restorations

Futoshi Komine^{1,2)}, Markus B. Blatz³⁾ and Hideo Matsumura^{1,2)}

¹⁾Department of Fixed Prosthodontics, Nihon University School of Dentistry, Tokyo, Japan

²⁾Division of Advanced Dental Treatment, Dental Research Center, Nihon University School of Dentistry, Tokyo, Japan

³⁾Department of Preventive and Restorative Sciences, Robert Schattner Center, University of Pennsylvania School of Dental Medicine, Philadelphia, PA, USA

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Abstract: Zirconium dioxide (zirconia) ceramics are currently used for fixed restorations as a framework material due to their mechanical and optical properties. This review article describes the current status of zirconia-based fixed restorations, including results of current *in vitro* studies and the clinical performance of these restorations. Adaptation of zirconia-based restorations fabricated with CAD/CAM technology is within an acceptable range to meet clinical requirements. In terms of fracture resistance, zirconia-based fixed partial dentures (FPDs) have the potential to withstand physiological occlusal forces applied in the posterior region, and therefore provide interesting alternatives to metal-ceramic restorations. Clinical evaluations have indicated an excellent clinical survival of zirconia-based FPDs and crown restorations. However, some clinical studies have revealed a high incidence of chipping of veneered porcelain. Full-coverage zirconia-based restorations with adequate retention do not require resin bonding for definitive cementation. Resin bonding, however, may be advantageous in certain clinical situations and is a necessity for bonded restorations, such as resin-bonded FPDs. Combined surface treatment using airborne particle abrasion and specific adhesives with a hydrophobic phosphate monomer are currently reliable for bonding to zirconia ceramics. Further clinical and *in vitro* studies are needed to obtain long-term clinical

information on zirconia-based restorations. (J Oral Sci 52, 531-539, 2010)

Keywords: zirconia; fixed restoration; adaptation; fracture resistance; bonding; clinical performance.

Introduction

As esthetic restorative materials for crowns and fixed partial dentures (FPDs), all-ceramic systems can be used as alternatives to metal ceramic systems. During the last decade, zirconium dioxide (zirconia, ZrO_2) ceramics, which have superior mechanical properties, high flexural strength (>1 GPa) and fracture toughness ($K_{IC} = 9-10$ MN/m^{3/2}) (1), have been used increasingly for copings and frameworks of fixed restorations. The majority of zirconia frameworks have been made with yttria-stabilized, tetragonal zirconia polycrystal ceramics (Y-TZP). The yttria (Y_2O_3) ceramic is present at only 2% to 3% mol (2). A valuable feature of this Y-TZP ceramic is its "transformation toughening" effect (3). Due to their excellent mechanical properties, Y-TZP ceramics have been used widely for the zirconia balls in total hip prostheses since 1985 (4). In dentistry, Y-TZP ceramics have been used for orthodontic brackets (5) and endodontic posts (6) since the early 1990s. Dental CAD/CAM procedures have been developed to produce Y-TZP zirconia-based fixed restorations since the later 1990s (7,8).

Zirconia blocks can be milled at three different stages: green, pre-sintered, and fully sintered (9,10). The original frameworks milled from green-stage and pre-sintered zirconia blocks are enlarged to compensate for prospective material shrinkage (20-25%) that occurs during the final

Correspondence to Dr. Futoshi Komine, Department of Fixed Prosthodontics, Nihon University School of Dentistry, 1-8-13 Kanda-Surugadai, Chiyoda-ku, Tokyo 101-8310, Japan
Tel: +81-3-3219-8145
Fax: +81-3-3219-8351
E-mail: komine@dent.nihon-u.ac.jp

sintering stage (11,12). The milling of green-stage and pre-sintered zirconia blocks is faster and causes less wear and tear on the hardware than the milling of fully sintered blocks. Although fully sintered zirconia materials are extremely difficult and time-consuming to machine due to the increased hardness of the material, they are not subject to dimensional changes such as shrinkage after milling.

This article reviews the literature on the current status of zirconia-based fixed restorations, including the results of recent *in vitro* studies and the clinical performance of these restorations.

Laboratory status

Marginal and internal adaptation

The adaptation of most zirconia-based restorations fabricated with CAD/CAM technology is within the acceptable range for meeting clinical requirements (13-18). Some basic *in vitro* studies have evaluated the adaptation of single crown restorations in terms of clinical parameters for tooth preparation. Komine et al. (14) concluded that rounded shoulder or chamfer preparations were recommended for the finish line design of zirconia-based restorations, and favorable results were also reported by Comlekoglu et al. (18). The 90-degree shoulder preparation, which has a sharp axiokingival internal line angle, had a negative influence, since a scanning laser appeared not to completely irradiate the area of the axiokingival internal line angle (14). Increasing the convergence angles of the tooth abutments reportedly improved the internal (16) and marginal (17) adaptation of zirconia-based crowns. Using CAD software, Iwai et al. (16) found that computer-fixed cement spaces with might influence the marginal adaptation of zirconia-based crowns.

Zirconia-based restorations are basically fabricated using two methods, the CAD/CAM system and the CAM-only system. FPDs fabricated with the CAD/CAM system exhibit smaller marginal discrepancy values than those fabricated with the CAM-only system (19-21). Beuer et al. (20) reported the complex fabrication process and variability of manual procedures for the CAM-only system, such as definitive die preparation with a spacer, and stated that waxing and wax pattern removal from the die might cause differences in adaptation. In terms of the state of zirconia at milling, four-unit FPDs made from fully sintered zirconia have been reported to show significantly better marginal adaptation than FPDs made from pre-sintered zirconia (22). On the other hand, Att et al. (23) showed that milling of pre-sintered zirconia material yielded results superior to those for milling of fully sintered zirconia and green-stage zirconia. Moreover, Komine et al. (24) reported

that pre-sintered zirconia exhibited better marginal adaptation of four-unit FPDs than green-stage zirconia. Bindl et al. (19) found that the marginal adaptation of three-unit FPDs was not significantly influenced by the zirconia state at milling. Although there is currently no clear conclusion about this issue, these studies indicated the efficiency of CAD/CAM software for compensating the shrinkage of zirconia with sintering. Hence, milling of zirconia blocks in a pre-sintered state, resulting in lower wear rates of the milling tools and shorter milling time, should be weighed against the benefit that can be obtained by stable adaptation.

Some studies have evaluated the influence of porcelain firing cycles on the distortion of zirconia-based FPDs. Vigolo et al. (25) found that porcelain firing and glaze cycles did not affect the marginal adaptation of zirconia-based four-unit FPDs. In contrast, other studies have demonstrated that veneering procedures may have a significant influence on the marginal adaptation of zirconia-based restorations (23,26,27). The thermal incompatibility between framework material and veneering porcelain can be one of the reasons for distortion resulting from veneering porcelain firings (28). An *in vitro* study (27) has shown that the marginal distortion discrepancy of zirconia-based restorations layered with porcelain having a higher coefficient of thermal expansion (CTE) mismatch ($1.2-1.7 \times 10^{-6}/^{\circ}\text{C}$) was significantly less than that obtained with a lower CTE mismatch. In theory, findings contradictory to those of their study could be expected since a lower CTE mismatch may have an advantage in reducing the residual stress at the interface of porcelain and zirconia. Therefore, the influence of porcelain firing on marginal adaptation should be investigated in further studies.

Some studies have compared the adaptation of zirconia-based FPDs fabricated with different CAD/CAM systems. The Procera (Nobel Biocare) system exhibited better marginal adaptation than the Lava (3M ESPE) system (29,30). Meanwhile, Vigolo et al. (25) reported an opposite outcome in which the Lava system showed significantly smaller marginal discrepancy than the Procera or Everest (KaVo) system. Another study showed that Cerec inLab (Sirona) achieved better marginal adaptation than the Procera or DCS system (23). These differences were probably attributable to variations in the FPD fabrication procedures as well as the investigation designs (23,31).

Gonzalo et al. (31) found that marginal discrepancies for zirconia-based FPDs were significantly smaller than those for metal ceramics, and concluded that zirconia ceramic systems could be an alternative to metal ceramic systems. One study evaluated the influence of framework configuration on the marginal adaptation of four-unit

zirconia-based FPDs (24). It was found that the framework configuration influenced the marginal adaptation of anterior zirconia-based FPDs regardless of the CAD/CAM system (24). Furthermore, it was assumed that when FPDs are fabricated with partially sintered zirconia, a relatively straight configuration can be expected (24).

Fracture resistance

In 2001, Tinschert et al. (32) reported that the fracture strengths of zirconia-based three-unit FPDs were significantly (almost three times) higher than those fabricated with the ceramic materials IPS Empress (Ivoclar-Vivadent) and In-Ceram Alumina (Vita). That study (32) and others (33-35) have indicated that zirconia-based FPDs have the potential to withstand physiological occlusal forces applied in the posterior region, and may be interesting alternatives to metal-ceramic restorations. The most common fracture pattern of tested zirconia-based FPDs was at the loading point and through one or both connectors (32-37). Therefore, the connector design appears to be crucial for the fracture resistance and longevity of zirconia-based FPDs. Pluengsombut et al. (38) demonstrated that the fracture was initiated from the gingival surface of the connector and propagated toward the pontic. As the radius at the gingival embrasure was increased from 0.6 to 0.9 mm, the fracture strength of zirconia-based FPDs with a connector dimension of 3×3 mm increased by 20% (39). Several *in vitro* studies have evaluated the fracture resistance of zirconia-based FPDs with a connector dimension of 3×3 mm, and obtained favorable results (33,40). A connector dimension of 4×4 mm has been recommended for zirconia-based FPDs in a clinical study (41) and an *in vitro* study (42). Clinically, the connector design should be determined according to material properties, anatomical limitations, hygiene considerations and esthetic expectations. Therefore, the dimension of the connectors and the radius of curvature at the gingival embrasure should be taken into account when designing zirconia-based FPDs.

From the viewpoint of minimal intervention, the reliability of inlay-retained (37,43) or resin-bonded zirconia-based FPDs (44-47) has been investigated. Zirconia-based three-unit inlay-retained FPDs with connector dimensions of between 9 and 12 mm² can be used clinically by considering the maximum chewing forces in the posterior region (37). The clinical performance of cantilever resin-bonded FPDs made of high-strength dental ceramics has been shown to be superior to that of two-retainer resin-bonded FPDs (44,46). In a clinical study, Komine and Tomic (45) observed no clinical complications at the 2.5-year follow-up examination of zirconia-based resin-bonded FPDs, and satisfactory functional and esthetic results were

achieved. On the other hand, Rosentritt et al. (47) assessed the fracture resistance of cantilever or two-retainer zirconia-based resin-bonded FPDs and found that the two-retainer FPDs had higher fracture resistance than the cantilever FPDs.

Although most studies evaluating the fracture resistance of zirconia-based restorations have obtained favorable results, a few studies of single crown restorations have shown a less than ideal outcome. Crown restorations made of Vita Mark II (Vita) exhibited higher fracture resistance than zirconia-based crowns and were expected to show better crack propagation resistance when used clinically (48). The authors considered that improvement of the framework-veneer bond would be needed, as fractures of the zirconia-based crowns tested occurred in the veneering porcelain (48). Reich et al. (49) reported that reduction in the framework thickness of single crowns from 0.5 to 0.3 mm resulted in a 35% reduction of fracture resistance.

Bonding and cementation

Conventional methods applied to the bonding to silica-based ceramics (i.e., acid etching and silane application) are not successful for bonding to high-strength ceramics (50). Therefore, numerous *in vitro* studies have investigated the bonding ability of adhesive systems to zirconia framework material. Initial suggestions for achieving superior bonding to a zirconia framework would be a combination of airborne particle abrasion and resin composites containing 10-methacryloyloxydecyl dihydrogen phosphate (MDP) monomer (50,51). In 1998, Kern et al. (50) achieved a durable bond to airborne particle-abraded ($110 \mu\text{m Al}_2\text{O}_3$ at 0.25 MPa) zirconia ceramics after 150 days of water storage with thermocycling using resin composites with a special adhesive monomer. Airborne particle abrasion, silane application, and use of a Bis-GMA resin cement resulted in an initial bond that failed spontaneously after simulated aging (50). These findings were verified by a long-term study in which specimens were subjected to two years of water storage and repeated thermocycling (51). As a different method of surface preparation for bonding, tribochemical silica coating (Rocatec System; 3M ESPE) of zirconia ceramics air-abraded with aluminum trioxide particles modified with silica has been introduced (52-56). Blatz et al. (57) evaluated the strength of bonding of different bonding/silane coupling agents and resin luting agents to zirconia ceramics. The authors demonstrated that application of an MDP-containing bonding/silane coupling agent to a zirconia surface abraded with Al_2O_3 particles afforded strong and durable bonding (57). To date, combined surface treatment with airborne particle abrasion and a specific adhesive

monomer with a hydrophobic phosphate monomer have proved reliable for bonding to zirconia ceramics (55-57). Nakayama et al. (58) demonstrated that treatment with MDP-containing monomer to zirconia ceramics enhanced the bonding strength obtained with TBB-initiated acrylic resin (Super-Bond C&B; Sun Medical).

Coating of silica-based ceramics on zirconia ceramics followed by silanization can successfully increase the strength of bonding to composite materials (59,60). This effect is probably due to the formation a siloxane network with silica or an increase in the roughness of the surface by fusing silica-based ceramics (59,60). Similarly, Aboushelib et al. (61) indicated that heat-induced maturation and selective infiltration etching can provide a strong and durable bond between zirconia ceramics and composite materials. However, since the above techniques were applied to the internal surface of zirconia-based restorations, adaptation of such restorations should be borne in mind for clinical use.

Several studies have indicated that zirconia-based single crown and FPD restorations may not require adhesive cementation (32,62). Rosentritt et al. (62) compared the fracture resistance of zirconia-based as well as metal alloy crowns, and found that the crown material or the cementation method had no significant influence on the fracture resistance. The authors concluded that adhesive cementation was not necessary for the application of zirconia ceramics (62). However, a resin bond to tooth and ceramics that has sufficient durability may become necessary in some clinical situations, such as compromised retention and short abutments. Some adhesive, resin-bonded treatment options (e.g., resin-bonded FPDs) rely on a strong and durable resin bond.

Clinical status

A number of clinical studies, within a five-year observation period, involving zirconia-based restorations have been published (41,63-78) (Table 1). Most of them evaluated zirconia-based FPDs for posterior missing teeth (41,63-72,74,76-78), while a few investigated zirconia-based single crowns (73,75). Zirconia-based FPDs exhibited promising clinical results with a high survival rate (over 95%) in most of the studies. It was found that posterior zirconia-based FPDs can be a reliable treatment modality with medium-term clinical application. Moreover, since zirconia-based FPDs exhibited survival rates similar to those of metal-ceramic FPDs, the authors concluded that zirconia ceramics could be a valid alternative to metal frameworks (72). Cantilever zirconia-based FPDs survived for three years (66). In another clinical study, the four-year survival rate was 92% for cantilever zirconia-based FPDs (71). It

was therefore concluded that the clinical performance of cantilever zirconia-based FPDs was promising (71). Figs. 1-3 show the clinical course of a cantilever zirconia-based FPD for a missing maxillary lateral incisor.

Some complications have been reported in clinical trials, such as veneering porcelain chipping, loss of retention, caries lesions, and loss of vitality (79). The most commonly reported complication is chipping or cracking limited to the porcelain veneer (Table 1). This chipping or cracking of zirconia-based FPDs is attributable to mechanical insufficiency of the veneering porcelain, inappropriate framework support for the veneer, and unfavorable shear forces between the zirconia framework and veneer material. Other contributing factors include a mismatch of the coefficient of thermal expansion, residual thermal stresses, and differences in the moduli of elasticity between the zirconia and the veneering material. To overcome some of these complications, the "overpressing technique", where a specific ceramic is pressed onto the zirconia framework, has been introduced (80). Beuer et al. (76) demonstrated that the overpressing technique for veneering porcelain resulted in no chipping, and appeared to be reliable in terms of the veneer outcome. With the aim of decreasing the incidence of cohesive porcelain fracture and other types of failure, Marchack et al. (81) showed that full-contour waxing can be effective in conjunction with dual-scanning to ensure an optimal coping design and appropriate porcelain thickness. The framework should be anatomically designed to provide support for the veneering porcelain. Kobayashi et al. (82) evaluated the strength of bonding of an indirect composite material to zirconia ceramics, and indicated that the indirect composite material could be a promising alternative veneering material for zirconia-based restorations.

Zirconia-based restorations can allow the use of traditional cementation procedures because of their high fracture resistance. In clinical studies, zinc-phosphate cement (40,66,67,75), glass-ionomer cement (70,73,74,76), resin-modified glass-ionomer cement (63,69), and resin-based luting material (64-68,75) have been used for placement of zirconia-based FPDs. Clinical results indicate that the type of luting agent employed may not influence the durability of zirconia-based restorations. In order to obtain an excellent esthetic outcome for a subgingival preparation design, adhesive cementation under dry conditions can be a challenge. In addition, removal of excess resin-based luting material in the subgingival area can be difficult. However, adhesive cementation would be expected to provide stability for zirconia-based restorations, and is necessary for resin-bonded restorations or short abutments.

Table 1 Details of clinical studies for zirconia-based fixed restorations

Authors, year, Ref. No.	Material	Type of restoration	Follow-up periods	Sample size	Framework fracture (%)	Veneering porcelain fracture (%)
Vult von Steyern et al. 2005 (41)	DC-Zirkon (DCS Dental)	3-5 unit FPD	2 years	20	0	15
Raigrodski et al. 2006 (63)	Lava (3M ESPE)	3-unit FPD	2.5 years	20	0	25
Sailer et al. 2006 (64)	Cercon Base (Dentsply)	3-5 unit FPD	3 years	46	0	13
Sailer et al. 2007 (65)	Cercon base	3-5 unit FPD	5 years	33	2.2	15.2
Tinschert et al. 2008 (66)	DC-Zirkon	3-5 unit FPD	3 years	65	0	6
Molin et al. 2008 (67)	Denzir (Cad.esthetics)	3-unit FPD	5 yeras	19	0	30
Crisp et al. 2008 (68)	Lava	3-4 unit FPD	5 years	38	0	3
Edelhoff et al. 2008 (69)	DigiZon (AmannGirrbach)	3-6 unit FPD	3 years	22	0	9
Schmitter et al. 2009 (70)	Cercon base	4-7 unit FPD	2 years	30	3	3
Wolfart et al. 2009 (71)	Cercon base	3-4 unit FPD	4 years	58	0	5
Sailer et al. 2009 (72)	Cercon base	3-5 unit FPD	3 years	36	0	25
Cehreli et al. 2009 (73)	Cercon base	Single crowns	2 years	15	7	0
Schmitt et al. 2009 (74)	Lava	3-4 unit FPD	3 years	27	0	11
Örtorp et al. 2009 (75)	NobelProcera (Nobel Biocare)	Single crowns	3 years	204	0	2
Beuer et al. 2009 (76)	Cercon base	3-unit FPD	3 years	21	5	0
Beuer et al. 2010 (77)	ZirCAD (Ivovlar Vivadent)	Single crowns 3-4 unit FPD	3 years	68	2	7
Roediger et al. 2010 (78)	Cercon base	3-4 unit FPD	4 years	99	1	13



Fig. 1 Labial view of maxillary incisors before treatment. The left lateral incisor had a fistula around the root apex because of root fracture, and was finally extracted.



Fig. 2 Final aspect of a cantilever zirconia-based FPD.



Fig. 3 Labial view of the cantilever zirconia-based FPD after placement. Satisfactory esthetic and functional results were obtained.

In conclusion, zirconia-based restorations are a promising prosthodontic alternative to metal-based restorations and show excellent clinical performance based on medium-term observation and *in vitro* investigations. Nevertheless, chipping of the veneering porcelain on zirconia-based restorations has been reported as one of the major complications. Various approaches for overcoming this problem are currently being developed. Further research is necessary to validate these protocols and to provide additional long-term clinical information.

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