

The Zirconia: a New Dental Ceramic Material. An Overview

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Abstract: Yttrium tetragonal Zirconia polycrystals (Y-TZP) based systems are the more recent addition in to the high-strength all-ceramic systems that are used for crowns and fixed partial dentures. CAD/CAM produced Y-TZP based systems are being used and are said to be in demand in the aesthetic zone and in stress bearing regions as well. This systematic overview covers results of recent scientific studies and the specific clinical guidelines for its usage. The following paper also offers our clinical experience with Cercon[®] Y-TZP based material (DeguDent, A Dentsply Internatiol Co, Rodenbacher, Hanu.) in long span six unit's fixed partial denture (FPD) in an aesthetic zone.

Introduction

The name "Zirconium" comes from Arabic word "Zargon" which means "golden in colour". Zirconium dioxide (ZrO_2) was accidentally identified by German chemist Martin Heinrich Klaproth [1] in 1789 while he was working with certain procedures that involved the heating of some gems. Subsequently, Zirconium dioxide was used as rare pigment for a long time. It was the impure zirconium that was used as pigment. In late sixties the research and development of zirconium as biomaterials was refined. The first recommended use of Zirconium as a ceramic biomaterial in the form of ball heads for Total Hip Replacements (THR) has been documented. In the early stages of development, many combination of solid solution (ZrO_2 -MgO, ZrO_2 -CaO, ZrO_2 - Y_2O_3) were tested for biomedical application. However, in later years, research efforts converged more upon the development of zirconia-yittria ceramics combinations commonly known as Tetragonal Zirconia Polycrystals (TZP). TZP is being used as application in space shuttle, automobiles, cutting tools, and combustion engines because of its good mechanical and dimensional stability, such as mechanical strength and toughness.

In vitro evaluation of the mutagenic and carcinogenic capacity of the high purity Zirconia ceramic confirmed that it did not elicit such effects on the cells [2]. In 1990s, Zirconium material was used as endodontic posts [3] and as implant abutments [4, 5]. This heralded the use of Zirconium in to dentistry. Due to its excellent physical properties, white colour, and superior biocompatibility it is being evaluated as an alternative framework for full coverage all-ceramic crowns and fixed partial dentures (FPD).

Technical data see Table 1.

Structural properties

The transformation toughened Zirconia has unique properties such as high fracture toughness and strength. Zirconium is a polycrystalline ceramic without any glass component. It is a polymorph that occurs in three forms, monoclinic (M), cubic (C) and tetragonal (T). Pure Zirconia at room temperature is

monoclinic and stable till 1170 °C. Above this temperature it transforms itself into tetragonal and then further into cubic phase at 2370 °C. During cooling, a T-M transformation takes place at the temperature range of about 100 °C below 1070 °C. The phase transformation, which takes place during cooling, is associated with volume expansion of approximately 3–4%. This means that components made of pure zirconium oxide would burst due to volume increase of grains and tension.

In late 1929, Ruff and co-workers demonstrated the possibility of stabilization of C-phase at room temp by adding small amount of CaO. The addition of stabilizing oxides, like CaO, MgO, CeO₂, and Y₂O₃, to pure Zirconia allows generating multi phase materials known as Partially Stabilized Zirconia (PSZ). Gravie et al in their paper “Ceramic steel?” [6] showed how to make the best use of T-M phase transformation in partially stabilized Zirconium (PSZ) and in the process improves the mechanical and physical properties of the material. They even observed the tetragonal (T) phase of PSZ is in metastable state at room temperature. The state is metastable because the transformation from **T** to **M** phase can be induced by external influence like tension or temperature. On PSZ, when tensile stresses acting at the crack tip induces transformation of metastable **T** phase to **M** phase. This transformation is associated with local increase of 3 % to 5 % in volume. This increase in volume results in localized compressive stresses being generated around and at the crack tip. Thereby squeezing the crack. This physical property is known as transformation toughening.

Design and manufacture of Yttrium Tetragonal Zirconia Polycrystals (Y-TZP) based restoration

A technician using either the traditional wax-up technique can design the Y-TZP-based framework for crowns or FPDs, or by advanced Computer assisted design (CAD) using computer and special software provided by the manufacturers.

Table 1 – Technical data [1]

Property	TZP Material
Colour	White
Chemical compositions	Zirconium oxide and Yttrium oxide 3 mol% Hafnium oxide < 2% Aluminium oxide + Silicone oxide <1% Total 100%
Density gcm ⁻³	>6
Porosity %	<0.1
Bending strength MPa	900–1200
Compression strength MPa	2000
Fracture toughness K _{IC}	7–10
Coefficient of thermal expansion K ⁻¹	11 × 10 ⁻⁶
Thermal conductivity WmK ⁻¹	2
Hardness HV 0.1	1200

This designing software is unique and different from individual Y-TZP based manufacturers. Cercon smart ceramic system (DeguDent GmbH, Germany.) utilizes conventional waxing method for designing infrastructure for crowns and bridges with specific thickness. A special Laser scanner scans the wax pattern and the data are transferred in to the Computer Aided Manufacturing (CAM) unit. This data is then utilized for milling the framework from partially sintered Y-TZP blanks. The LAVA system [7] (3M ESPE Dental Products, St. Paul, MN) and DCM-Precident (Direct Ceramic Machining Process, ETH Zurich, Switzerland) systems use different types of CAD software with different designing options and features. LAVA and Cercon systems uses partially sintered blocks of Y-TZP for milling the framework. But DCM (Direct Ceramic Machining Process, ETH Zurich, Switzerland) uses fully sintered blanks or HIP (hot isostatically pressed blanks).

When the partially sintered blanks are used, sintering shrinkage of 20 to 25 % has to be compensated by increasing framework size to attain good marginal fit [8, 9]. The system that uses fully sintered blank (HIP) takes longer time for milling due to increased hardness of blank. Studies show superior marginal fit by virtue of not having sintering shrinkage [8]. The cad/cam system uses contact scanning or laser to record the details of the prepared tooth model. Manufacturers who uses contact scanning, claims that digitization of details of prepared tooth are not as accurate as non-contact scanning by laser. However, AnnPersson *et al* [10] found that repeatability and accuracy of non-contact scanning was similar to contact scanning the mean difference was being 10 μm . The precision of the fit for prosthetic restoration is dependent on multiple factors. They can be, manufacturing process, tooth preparation, impression and fabrication of dental cast.

Clinical guidelines

Appropriate measures have to be taken while selecting the patient in addition to detailed intra oral examination as part of diagnosis. Criteria for patient selection are interocclusal space, para-functional habits and mobility of the tooth. The assessments of the criteria mentioned above are of utmost importance. The strength of Y-TZP is about 900–1200 MPa and flexural strength (K_{IC} value) of ranges between 8 to 12 $\text{Mpa}/\text{m}^{1/2}$ [11, 12]. In case of FPDs the minimum clinical height of prospective abutment (inter-proximal papilla to marginal ridge) should be 4mm [13], and total surface area of connector should be ranging from 7 to 16 mm^2 [12]. Clinically, these measurements can be registered using periodontal probe. Fractographic in vitro and in vivo studies showed that the mode of failure of all ceramic FPDs were the vertical fracture of connector at pontic region [14]. When there is a clinical situation wherein, the increased mobility of abutment teeth contributes to the fracture of FPDs.

Contraindication

- As cantilever pontic
- In class II div II malocclusions patients, due to deep bite there will be insufficient space for labo-lingual connector width.
- Mesial tilting of abutment tooth with supra erupted teeth, which cannot be corrected with minimal enameloplasty.
- Very short clinical crown that does not permit height of connector (occlusal-gingival).

Y-TZP based frameworks are white in colour. This can be of clinical limitation for its use in aesthetic zone. To overcome these problems systems like LAVA (3M ESPE), the framework for crown and bridges can be stained in to 1 of 7 shades of Vita-Lumin shade guide before sintering. This staining allows the achievement of the final shade from intaglio surface to external surface of veneering ceramic. And LAVA system is comparatively much translucent than other contemporary systems [12]. Due to shading possibility of framework in an aesthetically compromised surface, we can even avoid layering with veneering ceramic. Ability to control the shade of the core can also eliminate the need to veneer the lingual and gingival surface of connector area due to limited interocclusal clearance. But systems like Cercon[®] and DCS[®] – Precident uses white colored framework. Due to this, the latter two systems are difficult to use in an aesthetically demanding situations.

Tooth preparation guidelines are as comparable to metal fused to ceramic crowns and bridges preparations. It is advisable to use manufacturers recommendation and to use advised preparation kit. The axial reduction of approximately 1.2 to 1.5 mm, occlusal reduction should be 1.5 to 2.0 mm. Occlusal reduction should not be anatomical. The axial taper of crown preparation should be of 5 to 6 degrees. All the sharp edges of the crown need to be smoothed. The gingival finish line should be uniform and can be at the gingival margin or 0.5 mm sub gingival. Recommended cervical finish line is 0.8 or 1.2 mm deep chamfer or shoulder with rounded internal angle. Recent publications recommend that, for crown the chamfer finishing line and for bridges, the shoulders with rounded internal angle type design to be used for a favorable distribution of occlusal stresses to abutment teeth during function [15].

Full coverage Y-TZP based restorations can be cemented using conventional cements. It can also be bonded using adhesive cementation. Some studies do not strongly recommend using only adhesive cementation [16]. However, adhesive bonding is suggested alternative in some clinical situations, such as compromised retention and short clinical crown length of an abutment. Kern *et al* [17] in his study showed that by using airborne particle abrasion with 110 μm of Al_2O_3 at 2.5 bars pressure on the fitting surface of crown or FPD, combined with phosphate-modified resin cement Panavia 21 achieved highest bond to Zirconia and tooth.

Clinical Study results

Extensive laboratory studies confirmed the strength, superiority of zirconium-based restorations. Availability of long-term prospective clinical study results is limited for these new materials. Recently, interim results of long-term prospective clinical study of one of the Y-TZP materials LAVA (3M, ESPE) were reported [18]. This study consisted of 16 three unit posterior FPDs, at the end of 36 months showed good performance in terms of marginal integrity, marginal discolouration, and secondary decay. But minor chipping of veneer porcelain were observed which did not require any corrections. Another on going study of DC-Zirkon® (DCS® Precident system) of 18 patients, total 20 FPDs (three to five unit), at 3 year period showed 100% success rate in all regions of the mouth [15]. But same chipping fractures of veneer porcelain were observed. Long-term report of other ongoing studies will confirm the final clinical usage.

First Clinical Experience

This case report presents the usage of Cercon smart ceramics (DeguDent, Dentsply International Hanau), Y-TZP framework for the six-unit all-ceramic



Figure 1 – Initial appearance of patient.



Figure 2 – Metal fused ceramic bridge removed. Note the caries and discoloration of abutment teeth.



Figure 3 – Try-in of Cercon® framework.



Figure 4 – Six-unit bridge veneered and cemented with acceptable aesthetics.

bridge on 12, 13, 22, 23 region. Patient presented with complaints of discoloured upper anterior metal fused to ceramic bridge and exposed root surface of tooth 22. The Clinical examination revealed discoloured six-unit porcelain fused to metal (PFM) bridge and receded gingiva in 22, 23, 12, and 13. Detailed examination confirmed occlusal interference of old bridge during the functional movement of the mandible. Old PFM bridge was removed from abutment teeth. The cast metal root posts were also removed, and replaced with FRCPost [EnaPost, Micerium S.p.A Avegno, (GE), Italy.] and resin core [Ena-cem and Enamel Plus, HFO, Micerium S.p.A Avegno, (GE), Italy]. The abutment teeth crown preparations were modified with uniform, smooth, and deep chamfer gingival finish line. After gingival retraction, an A-silicone (A-Basic[®] PrePrint and Betasil vario, Omicron Dental GmbH, Schlosserstr.) impression was taken. Impression with bite registration was transported to the laboratory. A stone model and wax form of framework was prepared through conventional method. The completed six units Y-TZP based framework, were milled from one-piece white zirconium blank and sintered. These frameworks were clinically checked for fit, occlusion, labial profile and clearance for veneer ceramic and returned to the laboratory for veneering with compatible ceramic (Cercon[®], Ceram kiss). The final veneered bridgework was fixed on to the abutment teeth with Glass ionomer cement (Kavitan[®] Cem, SpofaDental). A favourable aesthetic result was achieved in this case.

Conclusion

Excellent material physical properties, biocompatibility, and superior aesthetics make Y-TZP a popular material among the contemporary all-ceramic material. Production method of such a material is simplified by utilizing high technology CAD-CAM technique. This also eliminates conventional lab procedures. CAD-CAM method of production produces consistent quality and superior marginal fit and also can satisfy critical aesthetic needs of the patients. This system scores over other systems because it does not require very complicated clinical procedures. Extensive in vitro and in vivo studies have confirmed high fracture resistance and its use in stress bearing areas. The five-year clinical follow-up studies that are in progress have shown a positive result at the end of first year.

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