REVIEW

A REVIEW OF ZIRCONIA CERAMICS

DATTA KUSUM[1] KAUR HARSIMRAN[2]

[1]Prof. and HOD
[2]Post Graduate Student

Dept. of Prosthodontics,
Pb. Govt. Dental College & Hospital,
Amritsar.

Address for Correspondence:
HARSIMRAN KAUR
Post Graduate student
Dept. of Prosthodontics,
Pb. Govt. Dental College & Hospital,
Amritsar.
e-mail: drsimran_83@yahoo.com

ABSTRACT

Zirconia is widely used to build prosthetic devices because of its good chemical properties, dimensional stability, high mechanical strength, toughness and Young's modulus (210GPa) similar to that of stainless steel alloy (193GPa). The mechanical properties of zirconia are the highest ever reported for any dental ceramics. On the other hand, its white colour, similar to the colour of natural teeth, makes it useful in esthetically important areas of the oral cavity and its ability to transmit light renders it a suitable material for esthetic restorations.[4]

BIOCOMPATIBILITY

The first proposal of the use of zirconium oxide for medical purposes was made in 1969 and concerned orthopaedic application. ZrO_2 was proposed as a new material for hip head replacement instead of titanium or alumina prosthesis.[5] Orthopaedic research focussed on the mechanical behaviour of zirconia, on its wear and on its integration with bone and muscle. Moreover, these first studies were largely carried out in-vivo because in-vitro technology was not yet sufficiently advanced. Prior to 1990, many studies were performed in which zirconia was tested on bone and muscles without any unfavourable results. Since 1990, many other studies have also been performed in order to obtain information about cellular behaviour towards zirconia. For implantation in bone zirconia should have favourable cellular response in terms of cell attachment, adhesion, proliferation and differentiation. Surface characteristic like topography, chemistry and surface energy play an important role in osteoblast adhesion on biomaterials.[6] In-vitro evaluation confirmed that ZrO_2 is not cytotoxic. Mutagenecity was evaluated by Silva and by Covacci and both reported that zirconia is not able to generate mutations of the cellular genome; in particular, mutant fibroblasts found on ZrO_2 were fewer than those obtained with the lowest possible oncogenic dose compatible with survival of the cells. Moreover, zirconium oxide creates less flogistic reaction in tissue than other restorative materials such as titanium. Inflammatory infiltrate, micro vessel density and vascular endothelial growth factor expression were found to be higher around the titanium caps than around the ZrO_2 ones. Also, the level of bacterial products was higher on titanium than on zirconium oxide. Zirconia can up or down regulate expressions of some genes, so that zirconia can be regarded as a self regulatory material that can modify turn over of the extracellular matrix.

DIFFERENT TYPES OF ZIRCONIA CERAMICS AVAILABLE FOR DENTAL APPLICATIONS

Although many types of zirconia containing ceramic systems are currently available, only three are used to date in dentistry.[7]

DISPERSION-TOUGHENED CERAMICS

An approach to advantageously utilize the stress induced transformation capability of zirconia is to combine it with an alumina matrix, leading to a zirconia- toughened alumina (ZTA). One commercially available dental product is In-ceram zirconia (Vident, Brea, CA) can be processed by either slip casting or soft machining. Initial sintering takes place at 1100°c for 2hours, prior to this porous ceramic composite being glass infiltrated. The glass phase represents approximately 23% of the final product. One of the advantages of the slip-cast technique is that there is very limited shrinkage. However, the amount of porosity is greater than that of sintered 3Y-TZP (Yttrium-tetragonal zirconia polycrystals) and comprises between 8 and 11%. This partially explains the generally lower mechanical properties of In-ceram zirconia when compared to 3Y-TZP dental ceramics.

In-ceram zirconia for machining is thought to exhibit better mechanical properties due to more consistent processing compared to the slip-cast ceramic. Conversely, significant high value for flexural strength is recorded for In-ceram zirconia processed by slip-casting (630±58MPa) compared to the machined material (476±50MPa). There was no significant difference in fracture toughness. The two materials exhibited a very similar micro-structure with large alumina grains (6µm long, 2µm wide) together with clusters of small zirconia grains (less than 1µm in diameter).

PARTIALLY STABILIZED ZIRCONIA

Although a considerable amount of research has been dedicated to magnesia partially stabilized zirconia (Mg-PSZ) for possible biomedical application, this material has not been successful mainly due to the presence of porosity, associated with a large grain size (30-60µm) that can induce wear. The micro-structure consists of tetragonal precipitates within a cubic stabilized zirconia matrix. The amount of MgO in the composition of commercial materials usually ranges between 8 to 10 mol%. In addition to a high sintering temperature (between 1680 and 1800°c), the cooling cycle has to be strictly controlled, particularly in the aging stage with a preferred temperature of 1100°c. Precipitation of transformable T-phase occurs during this stage, in which volume fraction is a critical factor in controlling the fracture toughness of the material. Due to difficulty of obtaining Mg-PSZ precursors free of SiO_2, magnesium silicates can form that lower the magnesium content in the grains and promote the T→M transformation. This can result in lower mechanical properties and a less stable material.

TETRAGONAL ZIRCONIA POLYCRYSTALS

Biomedical grade zirconia usually contains 3mol% yttria (Y2O3) as a stabilizer (3Y-TZP). 3Y-TZP has been used to manufacture femoral heads in total hip replacement. 3Y-TZP is available in dentistry for the fabrication of dental crowns and fixed partial dentures. The restorations are processed either by soft machining of pre-sintered blanks followed by sintering at high temperature, or by hard machining of fully sintered blocks. The mechanical properties of 3Y-TZP strongly depend on its grain size. Above a critical grain size, 3Y-TZP is less stable and more susceptible to spontaneous T→ M transformation whereas smaller grain sizes (<1µm) are associated with a lower transformation rate. Moreover, below a certain grain size (~ 0.2µm), the transformation is not possible, leading to reduced fracture toughness. Consequently, the sintering conditions have a strong impact on both stability and mechanical properties of the final product as they dictate the grain size. Higher sintering temperatures and longer sintering times lead to larger grain sizes.

Currently available 3Y-TZP for soft machining of dental restorations utilizes final sintering temperatures varying between 1350 and 1550 °C depending on the manufacturer. This fairly wide range of sintering temperatures is therefore likely to have an influence on the grain size and later the phase stability of 3Y-TZP for dental applications. Chevalier et al.[8] demonstrated that the presence of cubic zirconia is not desirable in 3Y-TZP for biomedical applications and is caused by uneven distribution of the yttrium stabilizer ions. The cubic grains are enriched in yttrium while the surrounding tetragonal grains are depleted and therefore less stable As mentioned earlier, restorations produced by soft machining are sintered at a later stage (i.e. following the forming steps). This process prevents the stress induced transformation from tetragonal to monoclinic and leads to a final surface virtually free of monoclinic phase unless grinding adjustments are needed or sandblasting is performed.

Several authors have reported that annealing at 900°C for 1h or relatively short heat treatments in the temperature range 900–1000°C for 1min induce the reverse transformation from monoclinic to tetragonal. This phenomenon was accompanied by the relaxation of the compressive stresses at the surface and a decrease in strength. The firing of veneering porcelain during the fabrication of dental restorations is therefore likely to promote the reverse transformation with the consequences. In addition, the reversibility of the transformation should not be confused as providing a mechanism for healing of the flaws.

The microstructure of 3Y-TZP ceramics for dental applications consists of small equi axed grains (0.2–0.5_m in diameter, depending on the sintering temperature). The mechanical properties are well above those of all other available dental ceramics, with a flexural strength in the 800–1000MPa range and fracture toughness in the 6-8MPa range. The Weibull modulus strongly depends on the type of surface finish and the processing conditions.

CONCLUSION

Although clinical long-term evaluations are a critical requirement to conclude that zirconia has good reliability for dental use, biological, mechanical, and clinical studies published to date seem to indicate that ZrO_2 restorations are both well tolerated and sufficiently resistant.[9] Ceramic bonding, luting procedures, ageing and wear of zirconia abutment should be evaluated in order to guide adequate use of zirconia as prosthetic restorative material. Patient selections, coupled with adequate clinical and technical protocols, are imperative in order to obtain good performance of these restorations.

BIBLIOGRAPHY

1.Denry I., Kelly J.R. State of the art of zirconia for dental applications. Dental materials 2008;24:299-307.

2.Manicone P.F., Iommetti P.R., Raffaelli L. An overview of zirconia ceramics: Basic properties and clinical applications. Journal of dentistry 2007;35:819-826.

3. Chevalier J. What future for zirconia as a biomaterial? Biomaterials 2006;27:535-543.

4.Ozkurt Z., Kazazoglu E. Clinical success of zirconia in dental applications. Journal of prosthodontics 2009;19:64-68.

5.Piconi C., Maccauro G. zirconia as a ceramic biomaterial. Biomaterials 1999;20:1-25.

6. Ko H.E., Han J.S., Bachle M., Jang J.H., Shin S.W., Kim D.J. Initial osteoblast-like cell response to pure titanium and zirconia/alumina ceramics. Dental materials 2007;23:1349- 1355.

7.Kelly J.R, Denry I. Stabilized zirconia as a structural ceramic: An overview. Dental materials 2008;24:289-298.

8.Chevalier J., Gremillard L. Ceramics for medical applications: A picture of next 20 years. Journal of European ceramic society 2009;29:1245-1255.

9.Kohal R.J., Att W., Bachle M., Butz F. ceramic abutments and ceramic oral implants. An update. Periodontology 2000 2008;47:224-243.

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