Zirconia - a boon to prosthodontics

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Introduction

With the expansion of porcelain-fused to- metal (PFM) procedures in the early sixties, metal–ceramic restorations have represented the "*gold standard"* for prosthetic dentistry, because of their good mechanical properties and quite pleasing esthetic results, along with an acceptable quality of their marginal and internal adaptation. The polycrystalline zirconium dioxide (zirconia) resulted valuable in prosthodontics, due to its exceptional mechanical properties and improved esthetics compared to metal–ceramics[1]. Zirconia is a ceramic material technically and an oxide chemically[2], insoluble in water and non-cytotoxic[3]. Studies, both in vitro and in vivo, showed its low adhesion to bacteria, even lower than on titanium[4]and favorable radio-opacity and a low corrosion potential[1].

Pure, unalloyed zirconia is polymorphic and allotropic at ambient pressure, presenting three crystallographic shapes at different temperatures: cubic (c) (from 2680 ◦C, the melting point, to 2370 ◦C); tetragonal (t) (from 2370 ◦C to 1170 ◦C); monoclinic (m) (from1170 ◦C to room temperature)[5]. Upon cooling when the spontaneous transformation from the (t)phase to the more stable (m) phase occurs, there is noticeable increase in the volume of the crystals (4–5%) that results in outstanding property of the zirconia[6]. When alloyed with other "cubic" oxides like MgO, CaO, Y2O3 and CeO2 (so-called "stabilizers"), the phase transformation could be prevented, allowing the zirconia crystals to be in their tetragonal or cubic shape at room temperature, in a thermodynamically metastable state. The subsequent volume increase of the crystals, inhibited by the surrounding ones, results in a favorable compressive stress that acts as a crack-limiter[1]. Such a mechanism has been termed as "transformation toughening" or "phase transformation toughening" (PTT)[7] and, along with the grain size of zirconia material, can explain why zirconia presents the highest flexural strength and fracture toughness compared to all the other ceramics.

Biocompatibility of zirconia

It is a biocompatible material, the release of residues and encapsulation by connective is less and is almost undetectable. Moreover, zirconia is known to be osseoconductive[8], which can be analysed with the help of scanning electron microscope (SEM). Zirconia which is a ceramic material facilitates bone formation as previously said it is ossoconductive in nature. Biocompatibility of dental biomaterials should be defined at analysis levels: in vitro and in vivo tests as well as clinical trials in human beings. Different cell lines like fibroblasts, lymphocytes, monocytes, and macrophages and also osteoblasts were used for in vitro tests on Zirconia, under different physical forms, for its toxic potency. Connective tissue, being the most pervasive one in the organism, mainly composed of fibroblasts and fibrocytes, was the first target investigated as regards biocompatibility of zirconia.

In the earlier 90s, Bukat and coworkers[9], using SEM, observed the adhesion and spreading of cells after direct contact of fibroblasts onto alumina and sintered zirconia ceramics (Ca-PSZ) disks with 30% of porosity. Later on, the influence of the physical form of materials was tested on in vitro biocompatibility by Ito and coworkers also[10].

Surface Analysis

Investigations are done on titanium and CoCrMo implants deposited with, zirconia with 4% CeO_2 and zirconia with 3% Y_2O_3 coatings, using the plasma spraying technique[11]. The adhesive strength of zirconia with 4% CeO_2 coating to titanium and CoCrMo substrates was higher than 68 MPa and which is significantly greater than that of zirconia with 3% Y_2O_3 coatings (32.3 MPa for titanium and 24.7 MPa for CoCrMo).

In another study Gahlert[12] et al examined zirconia implants with a machined or a sandblasted surface and compared them with SLA titanium implants. Surface analyses discovered that SLA titanium implant has highest surface roughness compared to zirconia implant and the machined zirconia implant.

Strength/ mechanical properties of Zirconia

Mechanical properties of zirconia have proved to be higher than all other ceramics for dental use, with a fracture toughness of 6–10MPa/m1/2, a flexural strength of 900–1200MPa and a compression resistance of 2000MPa[13]. An average load-bearing capacity of 755N was reported for zirconia restorations[14]. Fracture loads ranging between 706N[14], 2000Nand 4100N were reported. A recent in vitro investigation on zirconia

FPDs evidenced failure loads ranging between 379 and501MPa, thus higher than average human biting force, confirming a satisfactory serviceability of such frameworks.[15]

Performance

In contrast to other ceramics, zirconia has the potential to be used as an alternative material to metal for reconstructions where high loading forces are required, e.g., the posterior regions[16,17]. Currently, the data available on zirconia-based reconstructions confirm the load bearing capacity of this high-strength ceramic. A systematic review of the literature that evaluated all ceramic restorations survival rate in comparison with porcelain fused to metal and inside all ceramic group, with zirconia ceramic restorations.[18,19] 5 years survival rate of all ceramic restorations is 93.3%,whereas metal ceramic restorations have a 5 years survival rate of 95.6% when comparing Zr-ceramic restorations with other all ceramic systems, zirconia frameworks have proved to be more reliable. In dental healthcare, the use of zirconia implants, as treatment option, is a new topic compared to the other dental applications described.

Various applications of zirconia in dentistry

A number of researchers have introduced stabilized form of zirconia ceramic to be used in fabrication of post systems[20], because they have higher strength and fracture toughness than other ceramics. Kakehashi et al.[21] experimented with zirconia ceramic post clinically and reported a high success rate of zirconia post. Likewise, Paul and Werder[22] investigated zirconia posts and observed good clinical success of zirconia posts with direct composite cores after a mean clinical service of 4.7 years. The fabrication of either presintered or highly isostatic pressed zirconia frameworks, for crown and bridge has also been executed[23]. Besides above mentioned applications of zirconia in dental practice, zirconia has also been successfully used for the fabrication of esthetic orthodontic brackets[24]. Polycrystalline zirconia brackets, which reportedly have the greatest toughness amongst all ceramics, have provided an alternative to alumina ceramic brackets[25].

Zirconia as an implant material

The last three decades has showed an increase in the use of dental implants to replace missing teeth. In the late 1970s, the use of Titanium root form implants in the rehabilitation of the partially or completely edentulous patient has been mentioned in the work of Dr. Branemark. It is based on the fact that titanium implants "osseointegrate" with native bone and this material is capable of physical properties needed for oral function. The long term functional success and firm fixation of titanium implants is widely accepted in the clinical results, but its disadvantages include poor aesthetic late complications and soft tissue recession and bone loss especially in the esthetic zone.[26] These late complications have led to many implant collar design changes and development of white zirconia transgingival abutments, to achieve minimal soft tissue recession, to hide the metallic color and grey hue of the gingiva and in an attempt to minimize aesthetic failures.[27] Ceramic as a material for the dental implants is a definite alternative for the use of titanium material. One such material is Zirconia (Y-TZP), owning the capacity to osseointegrate[28] with very promising physical properties, such as flexural strength (900-1200MPa), hardness (1200 Vickers) as well as a threshold stress intensity factor which is favorable for long term firmness and success.[29]

Clinical and experimental studies on zirconia

Investigation showed a success rate of 93% of zirconia, after 2 years of observation period, with a favorable soft tissue response, in a limited sample size of 15 Cercon crowns(Dentsply Degudent, Hanau, Germany)[15]. Another study with a longer observation period (3 years), done on 204 Procera zirconia single crowns delivered in a private practice, showed a survival rate of 93%. In a 5 years study, survival rate of all ceramic restorations evaluated is 93.3%, whereas metal ceramic restorations have 95.6% survival rate. When comparing Zr-ceramic restorations with other all ceramic systems, zirconia frameworks resulted as the most reliable. Reviews of the literature on the survival rates of all-ceramic single crowns and fixed partial dentures in comparison with metal–ceramic restorations have been published[16], reporting, after 5years of observation, favorable survival rates (95.6%) for metal–ceramic prostheses, to be compared to a figure of 93.3% for all-ceramic restorations, among which zirconia based prostheses showed the best clinical performances and resulted as the most reliable all-ceramic systems. After 3 years of clinical service, almost all of the studies reported very good clinical outcomes for zirconia-based FPDs, with failure rates between 0% and 4.8%[26], showing a promising reliability of such restorations.

Limitations

Bulk fracture appears to be undetected in all studies done on zirconia. The fractures that have happened mostly involve connectors of multiunit prostheses (≥ 4) or second molar abutments[24]. Problems with the porcelain veneer seems to be a major problem in all studies. Minimum crazing or cracking with less loss of material has been reported in four separate systems 8, 15, 25 and 50% of prostheses after observation period of 1-2 years[25]. This may be due to that the difficulties are material related, as was the conclusion in one study of two systems exhibiting, respectively, 8 and 50% incidence of porcelain cracking[26]. This may also indicate that other factors such as thickness ratios or framework design play a role in porcelain cracking. For comparison, porcelain problems on metal–ceramic prosthesis over a 10 years observation period was reported to be on the order of 4% for a gold–palladium alloy, no higher than 6% for most alternative alloys, and only as high as 15% for one nickel-based alloy without beryllium[24]. Continous findings have been reported for another gold based alloy, with 98% completely intact porcelain at 5 years. Thus, porcelain–zirconia compatibility appears problematic in light of past experience with metal–ceramic systems[26].

Conclusion and Summary

There is increased use of all-ceramic single crowns and fixed partial dentures in Fixed Prosthodontics. In the last 20 years, dental ceramics provided, favorable and promising esthetic and mechanical properties. Further investigations regarding its bonding to veneering ceramic, cementation procedures, aging and wear and, above all, long-term clinical performance of zirconia are required to define its potential and limitations such an innovative, promising and intriguing restorative material.

References

1. Denry I, Kelly R. State of the art of zirconia for dental applications. Dent Mater 2008;24:299–307
2. Lughi V, Sergo V. Low temperature degradation–aging- of zirconia: a critical review of the relevant aspects in dentistry. Dent Mater 2010;26:807–20.
3. Dion I, Bordenave L, Levebre F. Physico-chemistry and cytotoxicity of ceramics. J Mater Sci Mater Med 1994;5:18–24.
4. Rimondini L, Cerroni L, Carrassi A, Torricelli P. Bacterial colonization of zirconia ceramic surfaces: an in vitro and in vivo study. Int J Oral Maxillofac Implants 2002;17:793–8.
5. Ruff O, Ebert F. Refractory ceramics: I. The forms of zirconium dioxide. Z Anorg Allg Chem 1929;180:19– 41.
6. Passerini L. Isomorphism among oxides of different tetravalent metals: CeO2–ZrO2; CeO2–HfO2. Gazzet Chim Ital 1939;60:762–76.
7. Garvie RC, Nicholson PS. Structure and thermodynamical properties of partially stabilized zirconia in the CaO–ZrO2 system. J Am Ceram Soc 1972;55:152–7.
8. Josset Y, Oum'Hamed Z, Zarrinpour A, Lorenzato M, Adnet Josset Y, Zarrinpour A, Lorenzato M, Adnet JJ, Laurent-Maquin D. In vitro reactions of human steoblastsin culture with zirconia and alumina ceramics. J Biomed Mater Res 1999;47:481–493.
9. Bukat A, Fassina P, Greco F, Piantelli S, Piconi C, Zaghini N. GSP-made Ca-PSZ for biomedical applications. In: Hulbert JE, Hulbert SF, editors. Bioceramics. Terre Haute. Indiana: Rose-Hulman Institute of Technology Publ; 1990. pp 355–366.
10. Ito A, Tateishi T, Niwa S, Tange S. In vitro evaluation of the cytocompatibility of wear particles generated by UHMWPE zirconia friction. Clin Mat 1993;12:203–209
11. Yang Y, Ong JL, Tian J. Deposition of highly adhesive ZrO(2) coating on Ti and CoCrMo implant materials using plasma spraying. Biomaterials. 2003;24:619–627.
12. Gahlert M, Gudehus T, Eichhorn S, Steinhauser E, Kniha H, Erhardt W. Biomechanical and histomorphometric comparison between zirconia implants with varying surface textures and a titanium implant in the maxilla of miniature pigs. Clin Oral Implants Res. 2007;18:662–668.
13. Yamauchi R, Morita A, Tsuji T. Pacemaker dermatitis from titanium. Contact Dermatitis. 2000;42:52–53.
14. Lüthy H, Filser F, Loeffel O, Schumacher M, Gauckler LJ, Hammerle CH. Strength and reliability of four-unit all-ceramic posterior bridges. Dent Mater 2005;21: 930–7.
15. Tinschert J, Natt G, Mautsch W, Augthun M, Spiekermann H. Fracture resistance of lithium disilicate-, alumina-, and zirconia-based three-unit fixed partial dentures: a laboratory study. Int J Prosthodont 2001;14:231–8.
16. Sadan, A.; Blatz, M.B.; Lang, B. Clinical considerations for densely sintered alumina and zirconia restorations: Part 2. *Int. J. Periodontics Restor. Dent*. 2005;*25*:343–349.
17. Sadan, A.; Blatz, M.B.; Lang, B. Clinical considerations for densely sintered alumina and zirconia restorations: Part 1. *Int. J. Periodontics Restor. Dent*. 2005;*25*:213–219.
18. Pjetursson BE, Sailer I, Zwahlen M, Hammerle CHF. A systematic review of the survival and compication rates of all-ceramic and metal ceramic reconstructions after an observation period of at least 3 years. Part I: single crowns. Clinical Oral Implant Research 2007;18:73–85.
19. Sailer I, Pjetursson BE, Zwahlen M, Hammerle CHF. A systematic review of the survival and compication rates of all-ceramic and metal ceramic reconstructions after an observation period of at least 3 years. Part II: fixed dental prostheses. Clinical Oral Implant Research 2007;18:86–96.
20. Kedici SP, Aksüt AA, Kílíçarslan MA, et al. Corrosion behaviour of dental metals and alloys in different media. J Oral Rehabil 1998;25:800-8.
21. Kwiatkowski S, Geller W. Preliminary consideration of the glassceramic dowel post and core. Int J Prosthodont 1989;2:51-5.
22. Michalakis KX, Hirayama H, Sfolkos J, et al. Light transmission of posts and cores used for the anterior esthetic region. Int J Periodont Restor Dent 2004;24:62-9.
23. Kakehashi Y, Lüthy H, Naef R, et al. A new all-ceramic post and core system: clinical, technical, and in vitro results. Int J Periodont Restor Dent 1998;18:586-93.
24. Luthardt RG, Sandkuhl O, Reitz B. Zirconia-TZP and alumina-- advanced technologies for the manufacturing of single crowns. Eur J Prosthodont Restor Dent 1999;7:113-9.
25. Kusy RP. Orthodontic biomaterials: from the past to the present. Angle Orthod 2002;72:501-12.
26. Steinemann SG. Titanium—the material of choice? Periodontol 2000. 1998;17:7–21.
27. Kohal RJ, Klaus G. A zirconia implant-crown system: a case report. Int Periodontics Restorative Dent. 2004;24:147–153.
28. Gahlert M, Gudehus T, Eichhorn S, Steinhauser E, Kniha H, Erhardt W. Biomechanical and histomorphometric comparison between zirconia implants with varying surface textures and a titanium implant in the maxilla of miniature pigs. Clin Oral Implants Res. 2007;18:662–668.
29. Depprich R, Zipprich H, Ommerborn M, et al. Osseointegration of zirconia implants compared with titanium: an in vivo study. Head Face Med. 2008;4:30.
30. Larsson C, Holm L, Lövgren N, Kokubo Y, Vult von Steyern P (2007) Fracture strength of four-unit Y-TZP core designed with varying connector diameter. An in-vitro study. J Oral Rehabil 34:702-709.
31. Vult von Steyern P (2005) All-ceramic fixed partial dentures. Studies on aluminum oxide- and zirconium dioxide-based ceramic systems. Swed Dent J Suppl 173:1-69.
32. Larsson C, Vult von Steyern P, Sunzel B, Nilner K (2006) All-ceramic two- and five-unit implant-supported

reconstructions. A randomized, prospective clinical trial. Swed Dent J 30:45-53.