REVIEW ARTICLE

Zirconia Abutments: A Quintessence of Modern Day Implantology

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ABSTRACT

Dental implants are considered an essential treatment modality for replacement of both single and multiple teeth. Titanium abutments which have been used as gold standard exhibit a dull grayish hue and give an unnatural appearance. The mechanical advantage together with esthetic gain over the conventional abutments has made zirconia abutments the state-of-the-art option available for use in the present day. This article intends to review these zirconia abutments for its property and its clinical implication in the modern day practice.

Keywords: Zirconia, Implant abutment, Esthetic abutment.

INTRODUCTION

Dental implants are considered an essential treatment modality which has demonstrated high success rates for replacement of both single and multiple teeth. However, this approach of rehabilitation is a clinical challenge especially in the anterior segment where esthetics has a prime importance. One of the most challenging scenarios is to satisfy the patient expectations both functionally and esthetically. The high esthetic demands lead to the fabrication of metal free restorations using ceramic that exhibits ideal properties of biocompatibility and esthetics.[1-3]

Abutments are the connecting element that attaches a crown, bridge or removable denture to the dental implant fixture. These abutments are commonly made from materials, such as titanium, surgical stainless steel and gold. Of these, titanium has been the gold standard and continues its impeccable service with respect to biocompatibility and its physical property. In spite of the success of these materials there has never been a dearth in the efforts to formulate the right ceramic material to overcome the inherent esthetic compromise in the use of metals, especially with regard to anterior restorations.

More modern abutments made from zirconia are now introduced in order to overcome the shortcomings and better complement the esthetics of a dental implant restoration. The objective of this review is to report the success of zirconia abutments compared to other contemporary materials used like titanium and alumina.

Esthetic Predicament

Rehabilitation in the esthetic zone is demanding, especially when subjected to a case with a gummy smile or a high lip line, to direct visual comparison with the adjacent natural teeth.[4,5] Titanium abutments display a dull grayish hue which may give the soft tissue an abnormal bluish appearance. The presence of a gray gingival discoloration may be attributed to a thin gingival biotype that is incapable of blocking reflective light from the metallic abutment surface.[6,7]

Gingival biotype switching has been suggested while using a metal abutment to increase the thickness of the gingiva; this thicker gingiva will block the reflective light from the surface of the abutment from showing through and thus improve the esthetic outcome.[8-11] Biotype switching, however, requires an additional surgical procedure, which is unpleasant for most patients.[10]

In light of this, recent years have shown a consistent trend toward esthetic improvements in implant restorative materials and have contributed significantly to the development of a new generation of ceramic abutments.

Ceramics Abutments

The increased demand from patient for high esthetic result, and clinician's need to achieve better treatment outcome, has considerably contributed to the development of a new generation of ceramic abutments. Ceramic abutments which were developed are available in prefabricated or customizable forms and can be prepared in the dental laboratory either by the technician or by utilizing computer-aided design (CAD) manufacturing techniques. The materials of preference are densely sintered high-purity alumina (Al_2O_3) ceramic and yttria (Y_2O_3)-stabilized tetragonal zirconia polycrystal ceramics. Alumina-based ceramics first broke into this 'metal bastion' and brought about the change that was so long desired and looked forward to. But as the first comer, its Achilles heel was that it possessed the risk of fracture during laboratory procedures and following abutment connection. To rein in this weakness yttrium oxide stabilized zirconia was introduced. It brought along several advantages like high flexural strength[12] (900-1,400 MPa) and desirable optical properties. This material proved its worth in mechanical properties and reliability

especially as a result of its stress-induced transformation toughening.[13-15]

Esthetics and Zirconia

Ceramics are the material of choice in simulating the natural dentition.[16] Their surface texture, translucency and color play a vital role in its capability to blend with its natural equivalent.[17] Translucency of a material is essential to present a natural appearance and is dependent on light scattering.[18] When light is being intensely spread and diffusely reflected it will give an opaque appearance. If only part of this light is scattered and most is diffusely transmitted, the material will appear translucent.[19] The amount of crystals within the core matrix, their chemical nature, and size of the particles; compared to the incident wavelength; will determine the amount of light that is absorbed, reflected and transmitted.[20] Zirconia possess maximal opaquing effect due to scattering of light by dispersed particles of zirconium oxide which are greater in size than the wavelength of light and with a different refractive index to the matrix.[21] Zirconia, though being a metal, has a very appreciable esthetic appeal due to its 'tooth color' and this factor alone takes it a long way in making it a very good choice as an implant abutment in the anterior region. Alumina abutments are composed of 99.5% pure alumina ceramic.[23] These abutments provide certain esthetic advantages when compared to the more whitish zirconia abutments. Zirconia has fewer shades and is more opaque in comparison yet, considering the esthetic requirement an implant abutment is asked to fulfill, it plays a fitting role. Alumina however, being a stiff material is often affected by technological problems like low resistance to bending forces. The mechanical properties of zirconia are in a league of its own and posses a significant advantage over other esthetic abutment. This combination of more than acceptable esthetics and its far reaching mechanical properties make this the gold standard of esthetic yet solidly reliable all-ceramic material available today.

Implications of Mechanical Properties

Zirconia is a high-strength ceramic, the yttria stabilized zirconia ceramic has twice the flexural strength of alumina ceramic (900-1400 MPa), a fracture toughness of up to 10 MPa/m$^{0.5}$, and a modulus of elasticity value of 210 GPa.[12,21] Compared to this, alumina ceramics have a flexural strength of 400 MPa, a fracture toughness value between 5 and 6 MPa/m$^{0.5}$, and a modulus of elasticity of 350 GPa.[21] The enhanced strength of zirconia (ZrO_2) can be explained by the microstructural differences, such as higher density, smaller particle size and polymorphic mechanism against flaw propagation.[12,22] The superior resistance of zirconia can be ascribed to the stabilizing effect of yttria, which allows for the processing of zirconia in the metastable tetragonal crystalline structure at room temperature (18° C-23°C). The tetragonal phase at room temperature allows for transformation to the monoclinic phase under stress and represents an efficient mechanism against flaw propagation. The transformation results in a compressive stress as the result of volume expansion and slows down further crack propagation, resulting in improvement of the mechanical properties (i.e. transformation toughening).[13-15]

It is the general understanding that ceramic abutments should demonstrate adequate resistance against the masticatory forces that rise during chewing or swallowing. Several studies reported a mean loading force of approximately 206 N and maximum biting forces of up to 290 N in the esthetic zone.[24,25] To achieve a fine restoration, the abutment should present resistance to fracture to ensure long-term success. In this perspective, zirconia abutments exhibit enhanced resistance compared to alumina abutments. Alumina abutments, though easier to prepare and effectively save time during definitive preparation, demonstrate a weak resistance to fracture. In an *in vitro* study, Butz et al[26]compared titanium reinforced zirconia and pure alumina abutments for their outcome after chewing simulation and static loading. Following fixation of the abutments and cementing of metal crowns, the specimens were exposed to 1.2 million cycles in a chewing simulator to simulate 5 years of clinical service. The median fracture loads were 294 N, 239 N and 324 N for the zirconia, alumina and titanium abutment groups, respectively. The authors concluded that titanium-reinforced zirconia as well as metal abutments achieved similar results, and can therefore be recommended as an esthetic alternative for the restoration of single implants in the anterior region. On the contrary, ceramic abutments made of alumina showed less favorable properties.

Recent studies have shown that alumina implant abutments, when used for fabrication of implant supported, short span fixed partial prosthesis; had a cumulative survival rate of 98.1% after an observation period of 5 years,[27] whereas alumina abutments used for the fabrication of implant-supported, single crowns; had cumulative survival rates between 93 and 100% after observation periods between 1 and 3 years.[28,29] Clinical studies on zirconia abutments confirmed that these abutments had a cumulative survival rate of 100% after observation periods between 4 and 6 years.[6,30]

All-Ceramic Restorations

Ceramic abutments can be restored using all-ceramic crown systems. The majority of clinical studies and case reports applied glass-ceramic crowns on alumina or zirconia abutment.[31-33] In an *in vitro* study by Yildirim et al[34] the fracture resistance of such restorations were evaluated. Alumina and zirconia abutments were prepared and restored with glass-ceramic crowns and placed on Branemark implants (Nobel Biocare, Gathenburg, Sweden). No artificial aging was applied to the test specimens. The statistical analysis showed significant differences between both groups, with mean fracture load values of 280.1 N for the group with alumina abutments and 737.6 N for the group with zirconia abutments. The fracture resistance in the zirconia abutment group was more than twice that in the alumina abutment group. Recent developments in CAD computer-aided manufacturing (CAM) techniques made it possible to use high strength ceramics to fabricate implant-supported all-ceramic restorations. The combination of a high-strength ceramic abutment and a high-strength all-ceramic superstructure system would enhance the overall resistance of the restoration. Unfortunately, no clinical data on the success of such restorations is available. In two other studies[35,36] conducted *in vitro*, the fracture resistance of different implant-supported all-ceramic restorations were evaluated and compared after chewing simulation and static loading. A total of 96 implants were divided into two test groups of 32 specimens each. The control group received titanium abutments whereas the implants in the test groups received Procera alumina abutments and Procera zirconia abutments with an internal connection design (Replace, Nobel Biocare). The abutments were prepared to receive standard maxillary central incisor all-ceramic crowns. The specimens were then exposed to 1.2 million cycles in a chewing simulator which applied varied load to simulate 5 years of clinical service. The highest fracture resistance value was found with the titanium abutment/alumina crown combination; whereas the smallest fracture resistance was found with the alumina abutment/zirconia crown combination. It was then concluded that all the abutment/crown combinations tested have the potential to withstand physiological occlusal forces in the anterior region. The aging effect through environmental stresses on the abutments like abutment grinding, chewing simulator including low temperature hydrothermal degradation was found to be responsible for the differences in the resistance to fracture, especially in the zirconia abutment groups.

Microbial Adhesion

Maintenance of restorations without marginal infiltrations or periodontal alterations is essential. Studies have proved zirconia to be satisfactory in this scenario. Scarano et al[37] reported a degree of coverage by bacteria of 12.1% on zirconia as compared to 19.3% on titanium. Rimondini et al[38] confirmed these results with an *in vivo* study, in which yttrium tetragonal zirconia polycrystals (Y-TZP) accumulated fewer bacteria than titanium in terms of the total number of bacteria and presence of potential putative pathogens such as rods. Surface roughness in this context appears very important. Kou et al[39] compared different polishing systems for zirconia and concluded that polishing creates surfaces similar to the just sintered ones and smoother than only grinding surfaces. These studies indicate that zirconium oxide can be suitable for implant abutment but more clinical and mechanical trials are necessary for a complete understanding of behavior of zirconia abutment throughout a long time period.

CAD/CAM

Advances in CAD/CAM technology has made it possible to more readily use zirconia in dentistry. This technology enables complex shapes to be milled out of premade zirconia blanks (or blocks), where the prepared abutment is first scanned, then using computer software, the desired framework is designed prior to milling.[40] There are two types of zirconia milling processes available: Soft milling and hard milling. Soft milling involves machining enlarged frameworks out of presintered blanks of zirconia, also called the 'green' state. These are then sintered to their full strength, which is accompanied by shrinkage of the milled framework by approximately 25% to the desired dimensions. Hard milling involves machining the framework directly to the desired dimension out of densely sintered zirconia blanks, these being the typical hot isostatic pressed (HIPed). However, the intense solidity of sintered zirconia, calls for a robust milling system that needs an extended milling period compared to the soft milling process, as well as placing heavy demands on the rigidity of the cutting instruments. The relative ease and speed of soft milling may be why more manufacturers chose this method to fabricate their dental zirconia products, while only a smaller number have used HIPed zirconia. Lava, Procera zirconia, IPS emax ZirCAD and Cercon are the most common systems utilizing soft milling. Systems that utilize hard milling of HIPed zirconia include DC-Zirkon and Denzir. Those that incline to soft milling claim that hard milling may introduce

microcracks in the framework during the process of milling. In contrast, those that support hard milling claim a superior marginal fit because no shrinkage is involved in their manufacturing process. Nonetheless, *in vitro* studies[41] validate the use of both HIPed and non-HIPed zirconia for implant abutments because of their high flexural strength and fracture toughness. The most widely utilized zirconia in dentistry, Y-TZP, has been establish to endure cyclic fatigue testing, based on the results of a study conducted by Studart et al[42] to have a lifetime longer than 20 years. Precision at the implant interface between the abutment and the fixture was assessed by comparing the rotational freedom of titanium, alumina and zirconia abutments with hexagonal external connections. Titanium and zirconia each flaunt an appreciably lower mean rotational freedom compared to the alumina abutment. The rotational freedom between abutment and fixture wound up to less than 3° for all of the abutments studied.[43] Vigalo et al[44] in their work reported that a zirconia abutment with a machined titanium base had a rotational freedom of less than 3°. Moreover, abutments milled by means of CAD/CAM systems can also be modified by the clinician to obtain a better marginal adaptation. In another study by Park et al[45] about 54 zirconia implant abutments were used over 4 years after which neither of them demonstrated structural failure. All were with good peri-implant tissue health as well. Though these studies indicate that ZrO_2 abutment could be suitable for clinical use for single tooth implant replacement, some aspects must be evaluated. In particular; possible wear behavior under loading at implant/abutment interface between titanium external connection and zirconia abutment must be investigated. As a matter of fact, wear can reduce the mechanical properties of zirconia affecting the fit between implant and abutment. Moreover, the resistance offered by zirconia on screwing abutment must be evaluated; minimal thickness of abutment walls must be established in order to perform adequate screwing torque of abutment without compromising zirconia abutment resistance.

CONCLUSION

The first proposal for the use of zirconium oxide for medical purposes was made in 1969 and concerned orthopedic application. ZrO_2 was then proposed as a new material for hip head replacement instead of titanium or alumina prostheses. Since, then this ceramic material has constantly been upgraded using state of the art research and development resulting in its use as a very important component in the most sophisticated dental rehabilitative technique we have evolved today–implant dentistry. Zirconia has after all held its own and even outshone some rival elements/materials with respect to mechanical properties, esthetics, bacterial adhesion, biocompatibility and overall reliability.

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