CURRENT STATE OF APPLIENCE ZIRCONIUM DIOXIDE IN BIOENGINEERING

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Abstract: This descriptive review presents current knowledge about the bioengineering use of a zirconium dioxide, the advantages and disadvantages of the material, and the prospects for research in this direction. The work reflects the success of the practical application of the zirconium dioxide as a material for dental structures and biological implants. Such practical characteristics, such as color-stability, chemical stability, good aesthetics, biocompatibility and durability, allowed to actively use the zirconium dioxide as a material for producing various dental structures. In comparison with other ceramics, the presence of high-performance of strength and fracture toughness of the zirconium dioxide enables the use of this material as an alternative material for the reconstructions in the readings with considerable loads. High hardness determines the zirconium dioxide as an excellent material for articular prostheses, because of its hardness, provides a low level of wear and excellent biocompatibility. However, along with positive characteristics, a widespread practical problem of using the zirconium dioxide in dentistry is a chip or fracture of veneering ceramics. It has also been reported that there is a shortage of orthopedic implants such as hydrothermal stability. The solution of such problems is indicated and the use of composite materials based on the zirconium dioxide, which allows to solve a similar problem, as well as to increase the service life and reliability of orthopedic implants by providing a higher fracture toughness and mechanical strength. The existence of such composite materials based on the zirconium dioxide provides a significant increase in the wear resistance of orthopedic implants, which is essential for successful prosthetics.

Keywords: zirconium dioxide; biocompatibility; ceramic materials; polycrystalline material; oral implants; materials for implants; clinical researches; dental prostheses; joint prostheses; wear.

1. Introduction

It is known that the zirconium dioxide is widely used for the manufacture of load-bearing functional structures in medicine and dentistry. Physical properties such as high fracture toughness and good flexural strength make it possible to a widely use this material in ceramic restorations. The zirconium dioxide is a polycrystalline material and occurs naturally as a mineral with a monoclinic crystal structure. When it is heated to 1170 °C, it passes into the tetragonal phase, and after 2370 °C – into the cubic one. Transformations between crystalline phases are reversible**.** When the phase changes, a change in the volume of crystal grains is observed, which is a key point in understanding of mechanical properties of the zirconium dioxide. The high degree of biocompatibility has made it possible for the zirconium dioxide to firmly establish itself as an ideal material for clinical use. Today it is known about the use of the zirconium dioxide as a material for the manufacture of bridges, crowns and add-ons on implants and teeth, as well as a hip prosthesis.

2. Methods

A systematic search was performed using the resource «NCBI», «PubMed» and manual examination to identify literature written on the subject of practical appliance of the zirconium dioxide in bioengineering direction, particularly as a material for prosthesis and dental implants. The key words for searching were «zirconium dioxide», «medical implants», «biocompatibility». Titles and abstracts of the searches were initially screened for possible inclusion in the review. The full text of all possibly relevant studies was obtained for assessment by each researcher.

3. Results

It is known that the zirconium dioxide is widely used in dentistry, in particular for the restoration of teeth, components of oral implants and oral implants made of zirconium dioxide [1].

Considering of whole ceramic materials available for dental healthcare, the zirconium dioxide offers the best mechanical properties today. Good results of orthopedic procedures have brought significant credibility in dentistry for the use of the zirconium dioxide as an auxiliary material (presumably as a substitute for alloys) for aesthetic restorations as well as for oral implants.

The zirconium dioxide found use as orthopedic implants for many years and more recently it appears in dentistry in the form of pin and rod systems [2–4] and orthodontic bracket [5], all-ceramic prosthetic restorations [6, 7], and more recently as a material for an oral implant [8–12].

Literary sources report that three ceramic systems are available for dental medicine containing zirconia: hardened zirconia alumina (ZTA), zirconium oxide, reinforced alumina (ATZ) and most widely used cations doped ITT dense (3 %) tetragonal polycrystal of the zirconium dioxide (3Y-TZP) [13], **Table 1**

Table 1
Mechanical properties of Zirconia Used in Dentistry

Material	Mechanical properties
3Y-TZP	Depend on grain size, which is denoted by sintering temperature
ATZ	The highest bending strength, known for ceramics (>800 MP at 1000 °C)
ZTA	Has less mechanical properties in comparison with 3Y – TZP

Nowadays all-ceramics materials are increasingly being used for the manufacture of crowns and fixed dental prosthesis (FDP). However, because of the presence of this disadvantage as lower bearing ability in comparison with metals, ceramic materials traditionally used in screening analyze with a lower load. The zirconium dioxide, in contrast to other ceramics, can be used as an alternative material for reconstructions in indications of high loads, for example in the posterior regions [14, 15], **Fig. 1.**

Fig. 1. Implants made by the zirconium dioxide

Manufacture of a material for all-ceramics constructions starts from waxy template or stamp, which is scanned by optical scanners or contact. The computer Noah software (Computer Aided Design – CAD) designs enhanced restoration and pre-sintered ceramic. The pre-sintered milled dental framework is completely sintered to form the final framework for further veneering with porcelain. The pre-sintering method allows to use of metal salts such as bismuth, cerium, iron, or a combination thereof, to paint pre-sintered blocks or milled finished frameworks. The pretreatment allows the creation of different shades of colors with the desired aesthetic effect for the final restoration. Also, for coloring ceramics, the method of adding metal oxides to the original ceramic powder can be used.

According to published clinical studies, the destruction rate of the zirconium dioxide scaffolds is low, ranging from 0 % to 4.8 % [16–20]. Moreover, fractures were reported in only two out of six studies [16, 21].

Nevertheless, despite high scaffold survival rates, zirconium dioxide-based reconstructions often occur in the presence of biological or technical problems [16–21]. The most common technical problem is the chipping or fracture of veneering ceramics [16–21]. This technical difficulty has been reported in most studies with a frequency of 8 % to 25 % [16, 19, 20]. Overall, however, the use of the zirconium dioxide as veneering ceramic is one of the main factors affecting long-term clinical outcome.

It is known a regularly used method for producing zirconia crowns, implant abutments and fixed dental prostheses is CAD/CAM milling of green state zirconia followed by sintering [22–27].

The high biocompatibility allows to use the material as a head of the hip bone for total hip replacement (THR) as an alternative to metal devices.

The zirconium dioxide is an excellent material for joint prostheses due to its hardness, which, in turn, means low wear and excellent biocompatibility. The use of biothermal materials in prosthetics, in comparison with structural implants made of metal alloys, provides a lower rate of wear of the implant components. Clinical studies have reported that wear was minimal when using zirconia-based ceramic femoral heads with ceramic cup inserts [28].

However, along with high biocompatible properties, the zirconium dioxide has such a significant disadvantage as hydrothermal stability. It is now known that yttrium-stabilized zirconium ceramics can be destabilized during steam sterilization by roughening the surface in the manufacture of femoral heads from zirconium ceramics due to hydrothermal transformation [29]. The appliance of composite materials allows to solve a similar problem and to increase the service life and reliability of orthopedic implants by providing a higher fracture toughness and mechanical strength. Literary sources report that there are such type of composites, as a system of phase-stabilized matrix made from the zirconium dioxide, reinforced with alumina particles, zirconia-reinforced alumina (ATZ) or a matrix of aluminum oxide reinforced with zirconium dioxide particles, alumina reinforced with zirconium dioxide (ZTA) [30]. The existence of such composite materials based on the zirconium dioxide leads to a significant increase in the wear resistance of orthopedic implants.

4. Discussion

This report represents a literary review, relating to the current success of using of the zirconium dioxide in biomedical applications. High biological and physical characteristics of the zirconium dioxide have opened up the possibility of widespread appliance of this material in such fields of medicine as orthopedics and dentistry. The introduction of the zirconium dioxide into the dental field has discovered new design possibilities for the use of ceramic restorations. The high degree of biocompatibility makes it possible to use the zirconium dioxide as the main material for the manufacture of hip joint prostheses. However, along with such positive qualities as high strength and crack resistance, there are also significant disadvantages of this material. These include hydrothermal stability and cleavage. The solution may be the practical use of composite materials based on the zirconium dioxide, which can significantly increase the durability and practical characteristics of implants based on the zirconium dioxide.

5. Conclusion

High biocompatibility makes it possible to introduce the zirconium dioxide in medicine, especially in dentistry and orthopedics, **Table 2**

Table 2
Mechanical properties of Zirconia

Threshold	Vickers Hardness	Strength	Toughness
3.5	1,200–1,300	1,000	5.4

A mechanical property, which is shown in table above, allows producing implants for total hip replacement and dental reconstructions. Such mechanical characteristics, as cleavage and hydrothermal stability, should be more investigated.

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