

Zirconia: the material of choice in implant dentistry? an update

Abstract

Although titanium is actually still the main material of choice to produce dental implants, there seems to be nowadays an obvious trend to fabricate these implants from more biocompatible materials. For the latter zirconia shows excellent conditions. Moreover, zirconia offers the dentist also the advantage to work with a more aesthetic solution. Although zirconia is already used in medicine for decades, there is still a lack of peer-reviewed research on the use of this material in dental implantology.

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Curd Bollen^{1,2}

¹Department of Periodontology Halitosis Implantology, Oral Clinical Center, Netherlands

²Parimplant Research Group, Netherlands

Correspondence: Curd Bollen, Department of Periodontology Halitosis Implantology, Oral Clinical Center, Eyckholtstraat 1-6116 BR Roosteren, Netherlands, Tel 00-316-5366-6824, Email dr.curdbollen@gmail.com

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Introduction

In a recent survey in Europe of over 250 people, by the Swiss implant company Straumann; most patients seem to prefer a ceramic implant (35%) over a titanium implant (10%), whereas still more than 50% had no specific preference. Presently however, the implant market is still largely dominated by titanium implants (>95%) and therefore ceramic implants are actually not more than a niche product. But as amalgam fillings were replaced by composites over the years, “white can become the new grey” as implant material.¹ But times are changing since established implant companies are manufacturing now their own ceramic implant-line: e.g. Straumann® (Pure Ceramic), Camlog® (Ceralog), Medentis® (ICX-white) and Bredent® (whiteSKY). For clinicians the ceramic implant solution is a valuable opportunity to expand their patient base, especially in challenging esthetic cases, moreover in patients with a thin gingiva type. Also the group of patients demanding for metal-free or bio-holistic implant treatments is increasing constantly. Whereas in the past the used ceramic materials were often of an “inferior” quality, the actual zirconia implants are at least as reliable as their titanium counterparts. But still, ceramic implants carry a questionable reputation, nevertheless the growing amount of peer-reviewed scientific publications. This update clarifies the actual situation.

History

Zirconium was discovered by the German chemist M.H. Klaproth in 1789. He also discovered uranium (1789) and cerium (1803). He described them as distinct elements, though he did not obtain them in the pure metallic state. Zirconium (Zr) is the chemical element with atomic number 40. The name is taken from mineral zircon, the most important source of zirconium. It is a strong, grayish-white, transition metal that resembles hafnium and titanium. It is, just as titanium and hafnium, part of the group of transition metals. Zirconium forms inorganic (zirconium dioxide) and organometallic (zirconocene dichloride) compounds. Five isotopes occur naturally, three of which are stable. Zirconium dioxide is called zirconia, which is often used in aerospace or as cutting tool in the watch industry.² This zirconia has outstanding mechanical properties, such as a high resistance

to scratching and to corrosion. It is a stable product and is highly biocompatible. Three different crystalline phases are determined: a monoclinic phase, a cubic phase and a tetragonal phase. The latter is the one that is clinically used. Yttrium, the chemical element with symbol Y and atomic number 39 (a silvery-metallic transition metal chemically similar to the lanthanides and often been classified as a “rare earth element”), is added for aging resistance and so the Ytria Tetragonal Zirconia Polycrystal (YTZP) is formed. This is a bioinert material with high mechanical properties: it is 6 times harder than stainless steel!

Moreover YTZP has some other eloquent characteristics:

- Electrical neutral.
- Low thermal conductivity.
- High resistance to high temperature.
- High thermal shock resistance.
- Chemical stability.

Due to all these criteria, zirconia is an excellent material for medical and dental applications.

Titanium vs zirconia

Straumann® made an internal comparison between their SLA-titanium implant and their ZLA-zirconia implant.³ The data showed clearly better characteristics for the zirconia implants (Table 1). Zirconia is highly biocompatible since it releases no ions and it creates an excellent osteoblast attachment and cellular proliferation which is responsible for a rapid growth of the bone-implant interface.^{4,5} These characteristics are in contrast with titanium that compromises cell viability and induces apoptosis, leading to a reduction of viable osteoblasts and a reduction of the bone quality.⁶ Moreover, in comparison to titanium, zirconia showed no induction of any adverse reaction or global toxic effect in vitro. Tests were performed on fibroblasts, lymphocytes, monocytes, macrophages, connective tissues, immunologic and bone tissues (Table 2).^{7,8}

Table 1 Comparison characteristics Ti grade IV and YTZP

	Ti Grade I	YTZP
Density	4,5g/cm ³	6,05g/cm ³
Hardness	250HV	1100-1500HV
Strength	680MPa	1200MPa
Elasticity	110GPa	200-220GPa

Table 2 Biological comparison titanium versus zirconia

	Titanium	Zirconia
Ion release	Yes	No
Toxicity	Low	No
Plaque adhesion	Low	Very low

When plaque adhesion was studied into more detail, only cocci and some short rods were found on zirconia surfaces. Motile microorganisms were not detected.⁹ It was also found that the early adhesion and colonization of bacteria on zirconia surfaces was much less than on titanium surfaces. These characteristics lead to a clear favorable soft tissue healing around zirconia.¹⁰ Since titanium can cause a non-specific immunomodulation, it induces autoimmunity, leading to a demonstrated sensitization to titanium.¹¹ The latter is not detected in zirconia. Studies show no difference in the initial osseointegration between titanium and zirconia. But when searching the literature, it is obvious that there is a lack of long-term studies involving zirconia implants.¹² When the perio-integration is evaluated, it is clear that there is a better fibroblast adhesion on zirconia, leading to a stronger cuff around the implants. This results in shallower sulcus depths with a mostly inflammation free environment.^{13,14}

Aging and radioactivity

At room temperature, zirconia is retained in a metastable tetragonal phase by the addition of stabilizing agents (e.g. yttria); the aging of zirconia consists in a return towards the more stable monoclinic phase. This transformation occurs preferentially at the surface of tetragonal zirconia ceramics. It has been shown that the tetragonal to monoclinic (t-m) transformation at the surface of zirconia ceramics is promoted by the presence of water molecules in the environment. Being subject to a volume increase, this t-m transformation induces the formation of microcracks at the surface, and an increase of the roughness. Microcracking leads to a decrease of the mechanical properties.^{15,16} This phenomenon is less applicable on the new generations of zirconia. Zirconia implants are slightly radioactive. Whereas a femoral head of nearly 100g deliver 0,5mSv/year, a dental implant (2g) is responsible for a dose of 0,01mSv/year. In comparison, the average normal yearly exposure is 2,4mSv/year, so this seems negligible.¹⁷

Aesthetics

As titanium can present a grey shadow through the gums or in case of gingival retraction (accelerated by the release of toxic titanium particles), zirconia has proven its aesthetic superiority in implant dentistry. Most of the zirconia implants come in an A2 color. Therefore they have an irrefutable advantage in patients with a thin biotype.¹⁸

Surface roughness and surface free energy

In the early nineties Quirynen and Bollen stated that 0,2µm is the

threshold surface roughness for microbial adhesion: a lower surface roughness has no extra impact on the bacterial accumulation on the surface, whereas a higher surface roughness is clearly connected to more plaque adhesion.¹⁹ A lot of recent studies focus on the surface roughness of zirconia in the oral cavity. When the surface roughness of crowns is considered, the different finishing protocols determine the final roughness:^{20,21}

- Glazed surface: 0,42-0,76µm.
- Surface finished with diamond burs: 0,89µm.
- Surface finished with diamond burs and then polished: 0,49µm.
- Only polished zirconia: 0,17µm.

The surface roughness of zirconia abutments is situated between 0,2 and 0,3µm.²² For implants there is difference between the body part (1, 2-1,6µm) and the collar (0,3µm). The smooth collar prevents the plaque adhesion and stimulates the perio-integration, whereas the rougher surface of the body is favoring the osseointegration.²³ The surface free energy of titanium is much higher than the surface free energy of zirconia, provoking more bacterial adhesion.²⁴

The market

There are several international players in the zirconia dental implant market. But only a limited number of these companies can offer peer-reviewed research on their products. Mostly there are only some in vitro studies or case presentations available

Z-systems® (PubMed - 5 publications: 2006-2016): Implants from Z-Systems® are made with the Zirkolith® process which as key advantages:

- The breaking strength depends on the manufacturing process. Zirkolith® ceramic implants are carefully made in several steps and then post-processed, offering a high breaking strength.
- The SLM® surface which has been developed and patented by Z-Systems® achieves a surface enlargement through increased macro and micro roughness. This leads to improved bone integration. Healing with the latest generation of Zirkolith® ceramics is over 98%, which is comparable to leading titanium implants.
- Zirkolith® ceramic implants are plasma sterilized, which is more gentle to the material.
- Zirkolith® ceramic implants can be ground in the mouth as with a natural tooth.

A clinical study by Blaschke and Volz shows that Z-system® implants are a feasible alternative to titanium dental implants. In addition to excellent cosmetic results, zirconia implants allow a degree of perio-integration / soft tissue response that is superior to titanium dental implants.²⁵

Straumann® (PubMed - 3 publications: 2012-2017): The Straumann® PURE Ceramic implant is a monotype design that consists of an implant and abutment made from zirconium-dioxide ceramic. The natural-looking ivory color makes the implant look more like a natural tooth and supports the clinician in cases of thin gingiva biotype or soft tissue recession. As part of Straumann's quality control measures: forces that exceed the maximum human bite capacity are applied. The Straumann® PURE Ceramic implant features a ZLA

surface, which is based on the well-documented Straumann® SLA surface. The ZLA and SLA surfaces have very similar topographies. Published research data indicates a similar healing pattern, healing time of 6 to 12 weeks and bone maintenance for the ZLA and the SLA surface. The ZLA surface demonstrates fast and predictable osseointegration, which is beneficial in successful implant treatment.²⁶

Swiss dental solutions- SDS® (PubMed - 1 publication: 2006): SDS® implants are made of the material TZP (tetragonal zirconia polycrystal). The implants are provided with an optimized “SLA-similar” surface (surface additively blasted with zirconia) and they have Dynamic Thread, which is tried and tested in all bone classes. The abutment can be ground deeply and then used as a standard abutment for cementing crown/bridge treatments, without additional work steps being required after direct impression. The two-piece implant system is based on over 15 years of experience in the development of ceramic implants. The load-bearing upper part of the implant and the implant abutment connection, have a very solid design. Its two-piece design allows for concealed healing along with high success rates, especially in the posterior region.²⁷

Ceraroot® (PubMed - 5 publications: 2007-2010): Ceraroot®, with over 10 year’s clinical follow-up, is the first ever zirconium implant with acid etched surface, providing an optimal macro-, micro- and nano-roughness: the ICE Surface®. It is a rough surface specially designed for achieving faster and stronger osseointegration compared to machined zirconium oxide implants. According to the long-term data that Ceraroot® has accumulated over the years, there seems to be no bone remodeling around Ceraroot® implants in patients with good oral hygiene from clinical cases performed back in 2003. Ceraroot® implants also demonstrate to be designed properly, as there hasn’t been any report of a patient fracturing the implant.²⁸

Zeramex® (PubMed – 4 publications : 2015-2016): Zeramex® represents an aesthetic and metal-free all-ceramic implant system that addresses a growing patient need. After four years of intensive research, the company presented in 2009 a two-part implant system made of white high-performance ceramic, with strong evidence, particularly in regards to the aesthetics and safety of the implants. Due to the anchoring of a two-piece system, the implant is initially hidden and can heal in the jawbone. After this, the prosthetic structures, abutment and crown, are applied. The two-part design is also a requirement for a flexible restoration with a lot of freedom. The stability of zirconium oxide is similar to titanium: strength tests (ISO 14801) show the high break resistance and durability.²⁹

Future

The dental implant market is continuously in evolution. An implant fitting the extraction socket could be the solution! At the present time there are over 250 implant companies, manufacturing over a thousand screw-type implants-yet not a single screw fits the tooth socket. BioImplant® is a dental implant specifically designed for immediate implantation. It is fundamentally different to screw-type implants, and cannot be compared with them in any way. The extracted root is scanned and milled in zirconia: exactly a copy of the lost root. The implant fits exactly into the tooth socket, and therefore any operation on hard or soft tissue, augmentation with cadaver/artificial bone, is absolutely unnecessary. Furthermore, only the periodontal ligament is removed, but never the bone. As there are no operations (the implant is tapped into the socket), there are no complicated guidelines to follow. Drilling guides, bone substitutes, membranes, and product-specific surgical sets and drilling sequences are not applicable. BioImplant®

is a single-piece implant, customized in form and color to the patient’s individual tooth, whether single or multi-rooted. The prefabricated crown stump can be adjusted at any time in the same way as a natural tooth.³⁰ This interesting evolution in implant dentistry is maybe the necessary nudge to help changing implantology into a “white, metal free” discipline.³¹

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None.

Conflicts of interest

The authors declare there is no conflict of interest.

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