Zirconium-dioxide as preferred material for dental implants

A narrative review: Part I

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Introduction

In a recent survey in Europe of > 250 people, by a respected dental implant company; most patients indicate to prefer a ceramic implant (35 %) over a titanium implant (10 %) to replace a tooth in their mouth, whereas 55 % had no specific preference in the latter. Presently however, the implant market is still dominated by titanium implants (> 95 %) and therefore ceramic implants are still considered as a sort of niche product in implant dentistry for the moment. But things are changing…

1

Dentistry, in particular implant dentistry, is constantly in evolution and what was pioneering yesterday is generally accepted today and probably outdated tomorrow. Researchers and scientists all over the world continue to look for new materials or enhance the characteristics of the available ones, in order to achieve better aesthetics, better manageability and/or better clinical results. This search occasionally leads to fundamental changes in current treatment paradigms. Whereas 30 years ago, dentists were still trained to use greyish, toxic amalgam to repair cavities caused by caries, today all these cavities are restored with white composite materials. This evolution not only banished the toxic mercury from the patient's mouth, but also addressed the aesthetic aspect of these dark grey fillings. Today, we have a wide variety of products to repair caries or to replace old fillings for higher aesthetic demands. Several other examples in dentistry are available, but as always, also in the early phase of composite as a restorative material, there are supporters and opponents of these novelties. Because dental professionals normally tend to be quite conservative, a large majority believed that amalgam would remain for always the gold standard as a filling material. Only the many evidence-based scientific reports and extensive publicity helped composites to become generally accepted over time. Meanwhile, amalgam is kept out of every modern dental practice.

2

A same sort of evolution is now slowly taking place in the field of dental implants. Although commercially pure titanium is still the gold standard to produce dental implants, there is now an important transition to manufacture implants from inert and more biocompatible materials.[1] In the early days of implant dentistry, Prof. Sami Sandhaus experimented with the implant material

Fig. 1: The late Prof. Sami Sandhaus, a pioneer in the field of ceramic implantology. **Fig. 2:** The German chemist Martin Heinrich Klaproth (1743–1817; Source: http://www.sil.si.edu/digitalcollections/hst/scientific-identity/explore.htm).

alumina (Fig. 1).[2] Due to insufficient tensile strength, this material was abandoned early, despite its high biocompatibility and clear aesthetic benefits.[3] Sandhaus was the absolute pioneer in ceramics as implant material. In the sixties of last century, he developed the Crystaline Bone Screw (CBS): the first 100 % metal-free and biocompatible dental implant. In the current group of used biomaterials, zirconia exhibits the best mechanical properties. Next to the biological advantages, zirconia also offers the possibility of working with significantly more aesthetic prosthetic solutions. Although zirconia is already used for decades in other medical disciplines (e.g. orthopaedics) and is scientifically well established, there is actually still a significant lack of sufficient peer-reviewed scientific research, in implant dentistry.

Fortunately, times seem to change since established implant companies are now manufacturing their own ceramic implant-lines, or bought small ceramic dental implant companies: Straumann® (Pure Ceramic®), Nobel Biocare® (NobelPearl®) and CAMLOG (CERALOG). Next to these 3 big companies, there are the smaller brands: Z-Systems®, Zeramex®, ZiBone®, Ceraroot®, TAV® Dental, SDS® etc. For many clinicians, ceramic implants represent a valuable alternative for expanding their patient base, especially in cases with challenging aesthetic demands and in cases where patients request metal-free dentistry or a complete bio-holistic approach.[4] Recently, a number of scientific professional organisations have developed around this specific theme: EACim (European Academy of Ceramic Implantology); ISMI (International Society of Metal Free Implantology; IAOCI (International Academy of Ceramic Implantology); and ESCI (European Society for Ceramic Implantology). The objective of all these societies is to establish dental implants, made of ceramics, on the basis of scientific and evidence-based foundations, as a reliable supplement and a meaningful extension of the treatment spectrum in addition to titanium implants.

History

Zirconium was first discovered by the German chemist Martin Heinrich Klaproth in 1789 (Fig. 2). Afterwards, Klaproth also discovered uranium (1789) and cerium (1803). He described them as separate elements, although he did not obtain them in the pure metallic state. Zirconium is the chemical element with the symbol Zr and with the atomic number 40 (Fig. 3). The name zirconium is taken from the name of the mineral zircon (related to Persian "zargun": gold-like or as gold). Zircon is the most important source from zirconium. Zircon is found primarily in Australia, Brazil, India, Russia, South Africa and the US. Worldwide resources exceed 60 million tonnes. The annual production is approximately 900.000 tonnes. Zirconium is a by-product of the mining and processing of the titanium minerals ilmenite and rutile, as

Fig. 3: Zirconium.

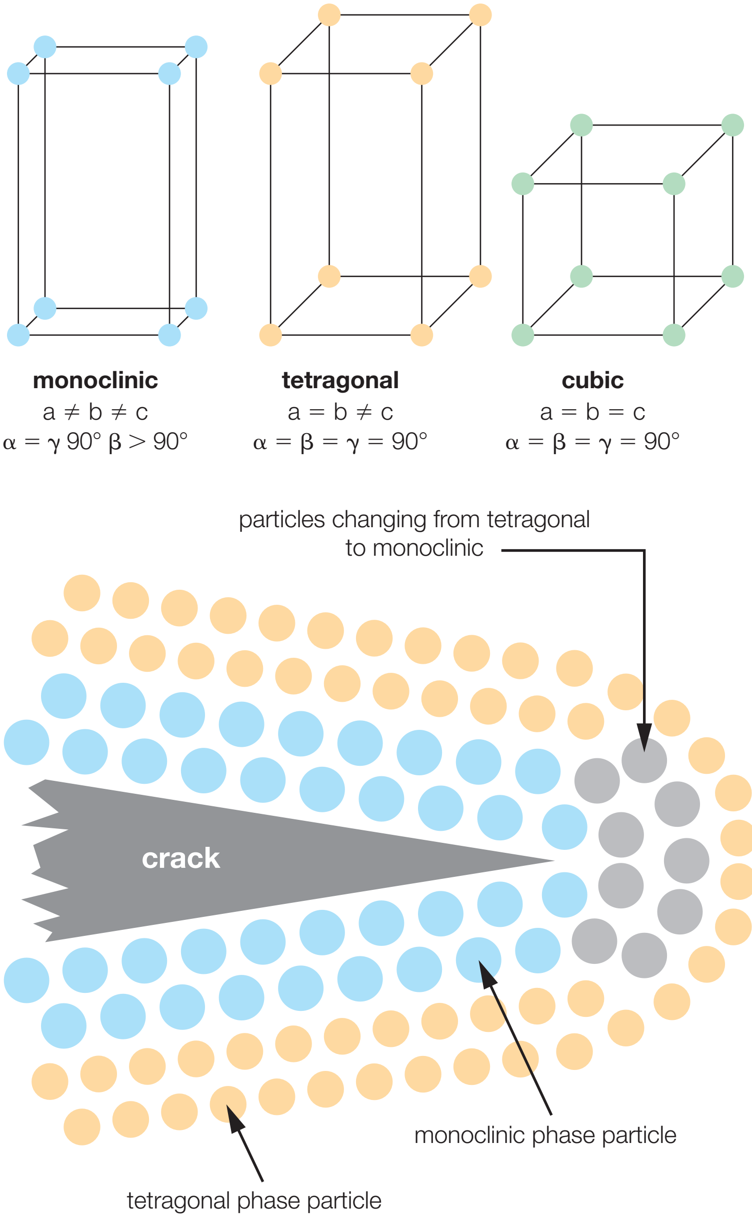

Fig. 4: The different phases of zirconia.

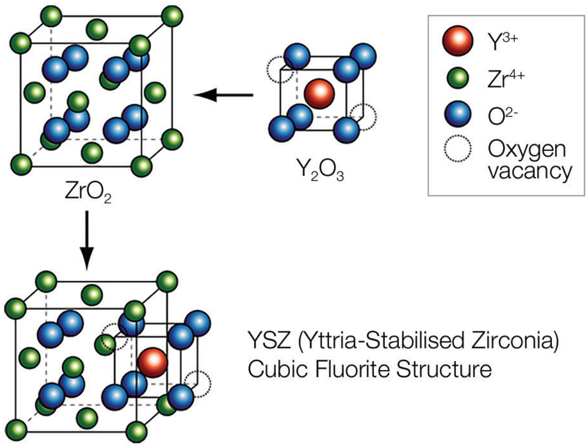

Fig. 5: The structure of YTZP (Source: http://www.doitpoms.ac.uk/tlplib/fuel-cells/printall.php).

well as of tin mining. Zirconium (40 Zr) is a lustrous, grey-white, very strong transition metal that closely resembles Hafnium (72 Hf) and to a lesser extent … Titanium (22 Ti). Zirconium is in industry mainly used as a refractory and opacifier, although small amounts are used as alloying agent for its resistance to corrosion.

Composition

Like all other transition metals, zirconium forms inorganic (zirconium-dioxide) and organo-metallic (zirconia-dichloride) compounds. There are five isotopes in nature, three of which are stable. The inorganic zirconium-dioxide (ZrO_2) is called zirconia. It is often used in aerospace or as a cutting tool in the watch industry and in surgery.[5] Moreover, zirconium-bearing compounds are used in many biomedical applications: not only in dentistry (crowns, implants and abutments), but also in orthopaedics (knee and hip replacements) and ENT (middle-ear ossicular chain reconstruction). Although zirconium has no biological role, the human body contains on average 250 milligrams of zirconium, with an average intake of 4,15 mg/d.[6]

Zirconia has excellent mechanical properties, such as high resistance to scratching and corrosion and a high resistance to load.[7] It is a very stable product and it is highly biocompatible. One distinguishes three different crystalline phases for zirconia (Fig. 4): a monoclinic phase, a cubic phase and a tetragonal phase. The phase is temperature dependent: monoclinic below 1,170 °C, tetragonal between 1,170 °C and 2,370 °C, and cubic above 2,370 °C. The trend is for higher symmetry at higher temperatures, as is usually the case. A small percentage of the oxides of calcium or yttrium stabilise in the cubic phase. The tetragonal form is the clinically used form. Yttrium, a chemical element with the symbol Y and atomic number 39 (39 Y, a silvery metallic transition metal), is generally added to improve the stability. This creates a bio-inert material with even higher mechanical properties: it is 6 times harder than stainless steel! That is why it is sometimes called (wrongly) ceramic steel.

The Yttrium-Tetragonal-Zirconia-Polycrystal (YTZP) shown in Figure 5, has even more interesting biological characteristics: it is electrically neutral and does not conduct electricity nor radiation; it has low thermal conductivity and high thermal shock resistance; and it is chemically totally stable.[8] Because of all these criteria, zirconia is an excellent material for medical and dental applications.

Editorial note: In the second part of this article, which is to be published later this year in the 2/20 issue of ceramic implants*, further material-specific aspects of zirconia will be discussed in depth, a market overview will be given, and a prognosis for future developments will be made.*

Literature

about the author

Prof. Curd Bollen obtained his DDS in 1992 at the Catholic University Leuven, Belgium. In 1996, he received his PhD and in 1997, he finished his M.Sc. in Periodontology & Implantology. In 2016, he completed the MClinDent programme at the University of the Pacific in the US. As for his active clinical work, Prof. Bollen specialises in periodontology, implantology and halitosis. He recently joined the College of Medicine & Dentistry in Birmingham, UK, as an Associate Clinical Professor.

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