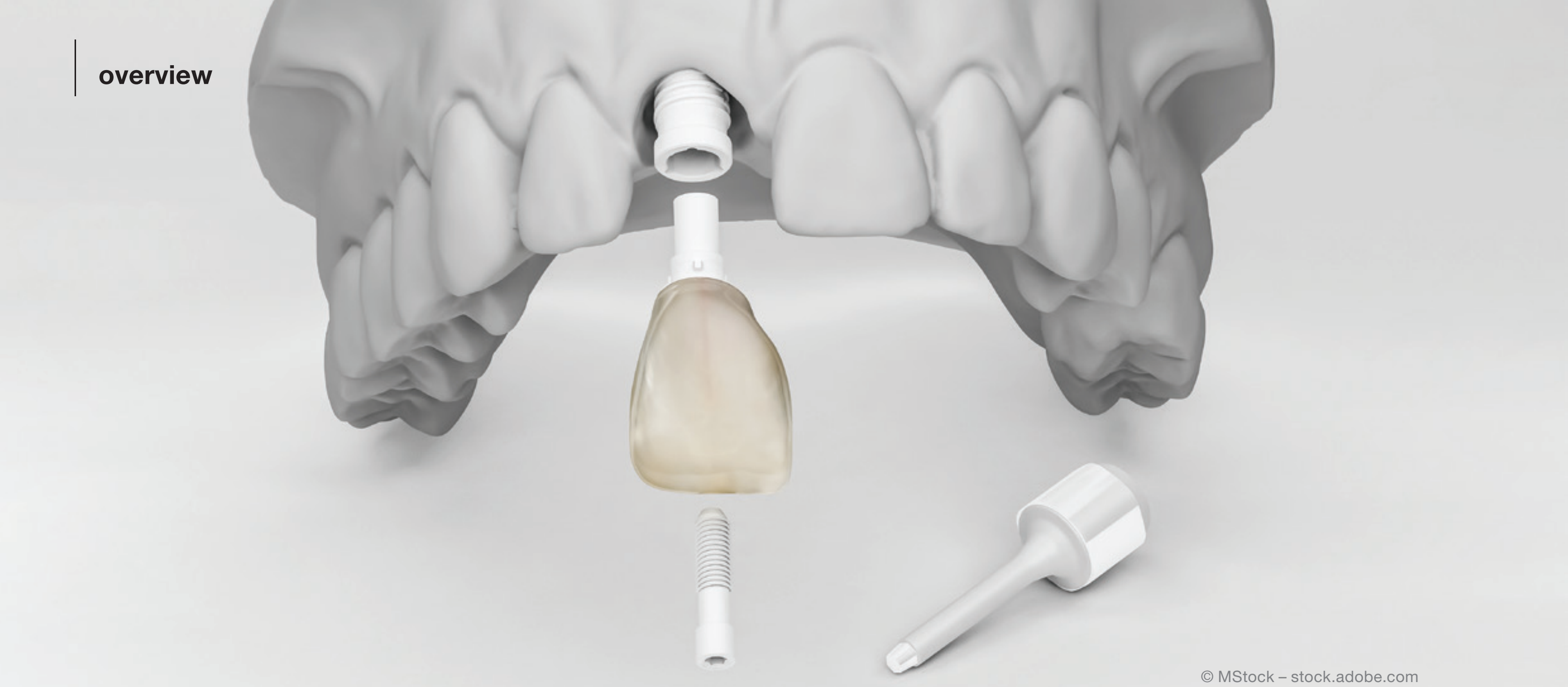

Zirconium-dioxide as preferred material for dental implants

A narrative review: Part II

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Part I

Editorial note: This is the second of a two-part article series. The first part, involving an introduction, a historical context and a chapter on composition, was published earlier this year in the 1/20 issue of ceramic implants. *It may be accessed as an online version by scanning the QR code to the left.*

	Titanium type IV	Y-TZP
Density (g/cm³)	4.5	6.05
Hardness (HV)	250	1,100–1,500
Strength (MP)	680	1,200
Elasticity (gp)	110	200–220

Table 1: Comparison between titanium type IV and yttria-stabilised tetragonal zirconia polycrystal (Y-TZP).

Characteristics

Zirconia has several other interesting characteristics what makes it an ideal product to apply in dentistry, not only for crowns, but also for dental implants and implant abutments.

General

The dental implant company Straumann® made an internal comparison between their SLA-titanium (sandblasted large-grit acid-etched) implant and their ZLA-zirconia (SLA but on zirconia) implant. Their data showed significantly better properties for the zirconia implants (Table 1).

Whereas alumina-oxide was a weak material that often led to fractures of the implants, zirconia tends to be stronger than titanium in the most relevant criteria. It is therefore a very suitable material for the production of dental implants. As mentioned already, zirconia is highly biocompatible, this is due to the rapid osteoblast adhesion and subsequent cellular proliferation that are responsible for an optimal bone–implant interface.[9,10] Biologists thought that these features contrast with titanium, which affects cell viability and induces apoptosis, leading to a reduction in viable osteoblasts and a significant reduction in peri-implant bone quality.[11] In addition, zirconia showed no induction of any toxic effect compared to titanium. Tests were performed on fibroblasts, lymphocytes, monocytes, macrophages, connective tissues, immunological and bone tissues (Table 2).[12,13]

	Titanium	Zirconia
Ion-release/corrosion	Y	N
Toxicity	low	N
Plaque adherence	low	very low

Table 2: Biological comparison between titanium and zirconia.

In several studies on intra-oral plaque formation, only cocci and some short rods were found on zirconia surfaces by dark phase contrast microscopy. Pathogens, such as mobile microorganisms (e.g. *Peptostreptococcus micros*) and spirochetes (e.g. *Treponema denticola*), were not detected on zirconia surfaces.[14] It also appears that the early adhesion and colonisation of bacteria on zirconium surfaces is much more limited than on titanium surfaces. Due to these characteristics, we see an extremely good soft-tissue reaction and a rapid healing of the soft tissues around intra-oral zirconia structures.[15]

Corrosion

Titanium is widely used in biomedical devices due to its recognised biocompatibility. However, implant failures and subsequent clinical side effects are still recurrent.[16] Body fluids and relative motion between implant and bone lead to synergistic degradation reactions, which cause failed implantation or adverse tissue reactions for implant materials used in human body. This was detected for several titanium alloys. This process can induce non-specific immunomodulation and autoimmunity, leading to a proven sensitisation to titanium; it has been suggested that some autoimmune diseases (e.g. multiple sclerosis and rheumatoid arthritis) may be caused by this sensitisation.[17]

It has been also labelled that up to 6% of the population is thought to have an allergic reaction to titanium.[18] This form of foreign-body reaction is also progressively associated with the loss of implants (non-integration or rejection) and the phenomenon of peri-implantitis. However, more scientific evidence is certainly needed here.[19] All these problems are rarely or not detected at zirconia implants.[20]

Osseointegration

Recent studies show little or no difference in the initial osseointegration between titanium and zirconia dental implants. However, when looking at this literature, it is clear that there is still a significant lack of long-term studies (randomised controlled trials) on zirconia implants.[21] When "periodontal integration" (healthy and firm soft tissue vs integrated material contact) is evaluated, it was described that there is a better fibroblast adhesion to zirconia, leading to a stronger "cuff" formation around these implants. This results in reduced pocket depths with a predominantly non-inflammatory environment.[22,23]

Ageing

At normal room temperature, zirconia is kept in a metastable tetragonal phase by the addition of stabilising agents (such as yttria). The ageing of zirconia consists of the return to a more stable monoclinic phase. This transformation takes place on the surface of ceramics of tetragonal zirconia. It has been shown that tetragonal to monoclinic transformation at the surface of zirconium ceramics is promoted by the presence of water molecules in the environment (e.g. saliva in the oral cavity). Subjected to an increase in volume, this stress transformation induces the formation of surface microcracks and therefore an increase in surface roughness. Microcracks can lead to a deterioration of the mechanical properties.[24,25] On long-term they can become macrocracks (chipping).

Radioactivity

Zirconia implants are slightly radioactive. Radioactivity of the ZrO_2 ceramics studied recently showed negligible radionuclide activity that can be considered lower than many hazardous radioactive appliances in our environment.[26] While a femoral head of about 100 g yields 0.5 mSv/year, a dental implant (2 g) is responsible for a dose of 0.01 mSv/year. By comparison, a transatlantic flight yields 0.16 mSV and the average normal exposure is 2.4 mSv/year. The additional radiation from implants (and crowns) therefore is not really worth mentioning.[27]

Material/Processing	Surface roughness
Glazed surface	0.42–0.76 µm
Surface finished with diamond burs	0.89 µm
Surface finished with diamond burs and polishing	0.49 µm
Only polishing	0.17 µm

Table 3: Surface roughness of zirconium crowns.

Manufacturer	Product
Nobel Biocare	NobelPearl
Straumann	PURE Ceramic, SNOW
Z-Systems	Z5m, Z5c, Z5s …
Dentalpoint	ZERAMEX XT, P6
Oral Iceberg	CeraRoot
SDS Swiss Dental Solutions	SDS1.2, SDS2.2 …
bredent	WhiteSky
TAV Medical	TAV White
CAMLOG	CERALOG
ZiBone	ZDI
Further companies include: VITA, WITAR, FairImplant, Medical Instinct, Champions …	

Table 4: Main products on the zirconia implant market.

Fig. 1: Shimmering titanium in a thin biotype. (© A. Sculean)[29]

Aesthetics

Since titanium can have a greyish shadow and twilight (Fig. 1), zirconia has proven its aesthetic values in implant dentistry. Most zirconia implants are available in an A2 colour. This gives them a significant advantage in patients with a thin biotype.[28] Implant companies hope to produce zirconia implants in more different white shades, adapted to the patient tooth colour, in the near future.

Surface roughness

Quirynen & Bollen found that 0.2 µm is the threshold surface roughness for microbial adhesion: an equal or lower surface roughness does not give any additional decrease nor increase in plaque growth, while a higher surface roughness is clearly linked to more plaque adhesion.[30] Several recent studies focus on the surface roughness of zirconia crowns in the oral cavity. When the surface roughness of crowns is investigated, the different finishing protocols determine the final roughness (i.e. the plaque retention potential; Table 3).[31,32]

The surface roughness of zirconium abutments is between 0.2 and 0.3 µm.[33] For zirconia implants, there is a difference between the screw section (1.2–1.6 µm) and the collar (0.3 µm). The smooth collar prevents plaque adhesion and stimulates periointegration, while the rougher surface of the screw section promotes osseointegration.[34]

Surface free energy

The surface free energy of titanium is much higher than that of zirconia, so therefore more bacterial adhesion can be detected on titanium surfaces compared to zirconia surfaces.[35,36]

Market

There are several international companies in the market that produce or sell zirconia dental implants (Table 4). However, only a limited number of these companies/

products can show peer-reviewed research associated with their products. Mostly, *in vitro* studies or case presentations are available.

Future perspectives

The field for dental implants is constantly evolving. An implant that fits directly into a fresh extraction cavity may well be the future solution. There are currently more than 250 implant companies producing thousands of different implant types, all of which unfortunately do not fit perfectly into the bone cavity after extraction. Extraction and direct implantation with a perfect fitting implant could be the future.

BioImplant® (FACE YOUR FACE) is a dental implant specially designed for immediate implantation after extraction. It is fundamentally different from screw-type implants and can in no way be compared to them. The extracted root is scanned and moulded in zirconia: a copy of the lost root(s). The implant fits exactly into the tooth socket and therefore does not require operations such as grafts, augmentations with autologous/xenologous/synthetic bone. Eventually some PRP/L-PRF could be applied additionally. Only the periodontal ligament is removed, but never the bone. Since there is no surgical procedure (the implant is inserted into the tooth socket), there are no complicated guidelines to follow. Drill guides, bone replacements, membranes, and product-specific surgical sets and drilling sequences are therefore not applicable. BioImplant® is a one-piece implant, adapted in shape and colour to the patient's individual tooth, both single and multiple rooted. The prefabricated stump can be grinded at any time in the same way as a natural tooth.[37] This evolution in dentistry may be the necessary push to help turn current implant dentistry into a "white and metal-free" discipline.[38]

Discussion

Will titanium soon be completely replaced by zirconia as the implant material of choice? Probably not! The material has still many advantages: cheap and simple production making the implants economically "affordable", a huge volume of scientific publications over a period of more than 50 years and numerous specific designs of screws for various indications. That's why titanium will certainly remain the gold standard as an implant material for the next decade.

Therefore, it is legitimate to conclude this narrative review with the question: Is zirconia just a temporary "ecological" hype? We believe it is certainly not. We consider there is a clear niche for zirconia implants that is likely to grow further once the material is fully developed, especially for aesthetic reconstructions in the anterior region (in patients with a thin gingival biotype); for gingival recessions where a white coloured implant is a great advantage; for patients with a proven titanium allergy (confirmed by an ELISA-test); and for patients who prefer a complete bio-holistic/metal-free dental approach, excluding (tribo-)corrosion and conduction of temperature or radiation by metals.

Having reviewed all the above, further research is certainly required to enlarge our understanding of these different materials and their applications. Three themes in particular need further to be explored: firstly, how "undesirable" the use of titanium as a dental implant material is for the general health; secondly, what the correlation is between the corrosion of titanium and the development of peri-implantitis; and thirdly, what the long-term clinical results of zirconia are as an implant material.

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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