Zirconia: the material of choice in implant dentistry?

Curd Bollen and **Maher Al-Masri** provide a narrative review into dental implant materials

Dentistry is constantly evolving; what was thought of as pioneering yesterday is generally accepted today.

Researchers and scientists continue to look for new biomaterials or enhance the characteristics of the available ones in order to achieve better aesthetics and clinical results. This search occasionally leads to fundamental changes in treatment paradigms. Literally on the surface, these changes can even be correlated with a shift in dental material colours. Whereas 25 years ago, dentists were trained to use silver-grey amalgam to repair caries, today all cavities are restored with white composite materials.

This evolution not only banished toxic mercury from the patient's mouth, but also addressed the aesthetic aspect of these silver fillings. In the early days of composite materials, only a very limited number of 'white tones' were available. Today, we have a wide variety of 'white-whiter-whitest' products to fill cavities or to replace old fillings for higher aesthetic demands.

In the early phase of composite as a restorative material, there were supporters and opponents of this novelty. Because dental professionals tend to be conservative, the majority believe that amalgam would remain the gold standard as a filling material. Only the many sound scientific reports and extensive publicity ensured that composites were generally accepted. So, amalgam has been considered, in the developed dental communities, a 'no-go' for restorative dentistry patients.

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Aims and objectives

To discuss the evolution of dental implant materials.

Clear expected outcomes

Correctly answering the questions on page 66 will demonstrate the reader understands how dental implant materials have changed in recent times, in terms of strengths and weaknesses.

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Topics: Implant dentistry

Developing dental implants

The same evolution is now conceivably taking place, rather slowly, in the field of dental implants.

Although commercially pure (CP) titanium is still the gold standard to produce dental implants (Brånemark et al, 1969), there is now an important trend to manufacture implants from more inert and biocompatible materials.

In the early days of implant dentistry, Sami Sandhaus (1971) experimented with the implant material alumina. However, due to insufficient tensile strength, this material was soon abandoned for intraoral use, despite its high biocompatibility and aesthetic benefits.

In the current group of biomaterials, zirconia exhibits excellent mechanical properties. In addition to the biological advantages, zirconia offers the possibility of working with significantly more attractive prosthetic solutions.

Although zirconia has been used in (orthopaedic) medicine for decades and is scientifically well established, there is still a disappointing lack of sufficient peer-reviewed scientific research in implant dentistry.

Ceramic implants

In a survey of 250 people, conducted by the Swiss implant company Straumann, more patients were found to prefer a ceramic implant (35%) to a titanium implant (10%). However, more than 50% do not yet have a specific preference.

At present, the implant market is still clearly dominated by titanium (more than 95%). As a result, ceramic implants are still a kind of niche product. But perhaps in implant dentistry, 'white' can become the 'new grey' (Bollen, 2016a).

Times are changing, especially since established implant companies such as Straumann (Pure and Snow), Camlog (Ceralog) and Nobel Biocare (Nobel Pearl) have each added a zirconia implant to their product portfolio.

For this purpose, the necessary know-how was purchased from the renowned Swiss manufacturers (Straumann – Z-Systems; Camlog – Axis; Nobel Biocare – Zeramex).

For many clinicians, ceramic implants represent a valuable alternative for expanding their patient base, especially in cases with challenging aesthetic demand. Furthermore, there has been a significant increase in the number of patients requesting metal-free dentistry or bio-holistic implant treatments in Europe and other developed countries.

Because, in the past, ceramics were often regarded as 'inferior' quality due to its reputation as brittle; they still have to deal with the prejudices, in spite of the slowly but steadily growing volume of scientific publications. In the meantime, current zirconia implants are proven to be at least as strong (fracture-strength) as their titanium counterparts (Cionca, Hashim and Mombelli, 2017).

A number of scientific professional organisations have also recently developed around this specific theme, such as the European Society for Ceramic Implantology (ESCI). The objective of the ESCI, as a neutral

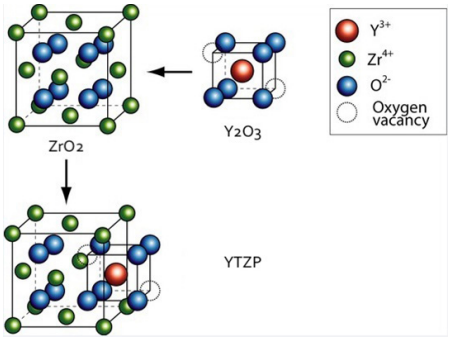

FIGURE 1: Structure of YTZP

	Titanium type IV	YTZP
Density (g/cm3)	4,5	6,05
Hardness (HV)	250	1100-1500
Strength (MP)	680	1200
Elasticity (gp)	110	200-220

TABLE 1: Comparison Ti type IV and Y-TZP

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

TABLE 2: Biological comparison titanium versus zirconia

and independent professional society, 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. (Visit www.esci-online.com for further details.)

Material composition

Zirconium was discovered by the German chemist Martin Klaproth in 1789. He also discovered uranium (in 1789) and cerium (in 1803). He described them as separate elements, although he did not obtain them in the pure metallic state.

Zirconium (Zr) is the chemical element with atomic number 40. The name is derived from the mineral zirconium, the main source of zircon.

It is a strong, grey-white transition metal that resembles hafnium and titanium. It is, like titanium and hafnium, part of the group of transition metals.

Zirconium forms inorganic (zirconium dioxide) and organo-metallic (zirconia-dichloride) compounds. There are five isotopes in nature, three of which are stable.

Zirconium-dioxide is called zirconia. It is often used in aerospace or as a cutting tool in the watch industry (Radhakrishnan et al, 2012). This zirconia has excellent mechanical properties, such as high resistance to scratching and corrosion. It is a stable product and highly biocompatible.

One distinguishes three different crystalline phases for zirconia:

1. A monoclinic phase
2. A cubic phase
3. A tetragonal phase.

The latter is the clinically used form. Yttrium, a chemical element with the symbol Y and atomic number 39 (a silvery metallic transition metal), is added to improve the stability. This creates a bioinert material with high mechanical properties: it is six times harder than stainless steel! That is why it is sometimes called (wrongly) ceramic steel.

This yttrium-tetragonal-zirconia-polycrystal (Y-TZP) (Figure 1) has even more interesting biological characteristics:

- It is electrically neutral and does not conduct radiation
- It has low thermal conductivity and high thermal shock resistance
- It is chemically stable.

Because of all these criteria, zirconia is an excellent material for medical and dental applications.

Titanium versus zirconia

Swiss company Straumann made an internal comparison between its SLA-titanium implant and its ZLA-zirconia implant. The company's data showed significantly better properties for the zirconia implants (shown in Table 1).

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 (Depprich et al, 2008; Olmedo et al, 2003). 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 (Bächle et al, 2007).

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 (Uo et al, 2003; Blaschke and Volz, 2006) (Table 2).

In several studies on plaque formation, only cocci and some short rods were found on zirconia surfaces. Pathogens, such as mobile microorganisms (eg, Peptostreptococcus micros) and spirochetes (eg, Treponema denticola), were not detected (Bollen et al, 1996). It also appears that the early adhesion and colonisation of bacteria on zirconium surfaces is much more limited than on titanium surfaces. Partly because of these characteristics, we see an extremely good soft-tissue reaction and a rapid healing of the soft tissues around zirconia (Hisbergues, Vendeville and Vendeville, 2009).

Since titanium can cause non-specific immunomodulation, it induces autoimmunity, leading to a proven sensitisation to titanium; it has been suggested that some autoimmune diseases (eg, multiple sclerosis and rheumatoid arthritis) may be caused by this sensitisation (Stejskal and Stejskal, 1999).

It is also thought that up to 6% of the population is thought to have an allergic reaction to titanium (Hosoki et al, 2018). 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 (Mombelli, Hashim and Cionca, 2018).

All these problems are rarely or not detected at zirconia implants (Holländer et al, 2016).

Studies show little or no difference in the initial osseointegration between titanium and zirconia. However, when looking at the literature, it is clear that there is a significant lack of long-term studies on zirconia implants (Kohal et al, 2009).

When 'periodontal-integration' 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 (Grössner-Schreiber et al, 2006; Degidi et al, 2006).

Ageing and radioactivity

At 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 a return to the more stable mono-clinic phase. This transformation takes place on the surface of ceramics of tetragonal zirconia. It has been shown that tetragonal to mono-clinic

FIGURE 2: Shimmering titanium in a thin biotype (copyright: Sculean A, 2017)

Material/processing	Surface roughness
Glazed surface	0,42-0,76µm
Surface finished with diamond burs	0,89µm
Surface finished with diamond burs and polishing	0,49µm
Only polishing	0,17µm

TABLE 3: Surface roughness zirconium crowns

Nobel Biocare	Nobel Pearl
Straumann	Pure Ceramic, Snow
Z-systems	Z5m, Z5c, Z5s...
Zeramex	XT – P6
Oral Iceberg	Ceraroot
SDS	SDS1.2 - SDS2.2
Bredent	Whitesky
TAV	W one-piece & W two-piece
Camlog	Ceralog
Zi Bone	ZDI
More: Vita, ICX, Witar, Fairimplant, Medical Instinct, Champions	

TABLE 4: Main players on the zirconia implant market

transformation at the surface of zirconium ceramics is promoted by the presence of water molecules in the environment (eg, saliva).

Subject to an increase in volume, this stress transformation induces the formation of surface micro-cracks and an increase in roughness. Micro-cracks can lead to a deterioration of the mechanical properties (Deville, 2003; Chevalier et al, 2011).

Zirconia implants are slightly radioactive. While a femoral head of about 100g yields 0.5 mSv/year, a dental implant (2g) 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 therefore seems negligible (Porstendörfer, Reineking and Willert, 1996).

Aesthetics

Since titanium can have a grey shadow and twilight (Figure 2), 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 (Jung et al, 2007).

Surface roughness and surface free energy

Quirynen and Bollen (1995) found that 0.2µm is the threshold surface roughness for microbial adhesion: an equal or lower surface roughness does not give any additional increase in plaque growth, while a higher surface roughness is clearly linked to more plaque adhesion.

Many 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 (Sabrah et al, 2013; Janyavula et al, 2013) (Table 3).

The surface roughness of zirconium abutments is between 0.2 and 0.3µm (van Brakel et al, 2012). For zirconia implants, there is a difference between the screw section (1.2-1.6µm) and the collar (0.3µm). The smooth collar prevents plaque adhesion and stimulates perio-integration, while the rougher surface of the screw section promotes osseointegration (Fischer, Schott and Märtin, 2016).

The surface free energy of titanium is much higher than that of zirconia, so more bacterial adhesion is observed on titanium compared to zirconia (Al-Haj Husain and Özcan, 2016).

Market

There are several international players in the market for zirconia dental implants (Table 4). However, only a limited number of these companies can show peer-reviewed research associated with their products. Usually, only in-vitro studies or case presentations are available.

Future perspectives

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

Bioimplant 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.

Only the periodontal ligament is removed, 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 (Anssari Moin, Hassan and Wismeijer, 2016). This evolution in dentistry may be the necessary push to help turn current implant dentistry into a 'white and metal-free' discipline (Bollen, 2016b).

Will titanium soon be completely replaced as an implant material? Absolutely not!

The material has 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.

Discussion

It is legitimate to concludes this 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, which is likely to grow further once the material is fully developed, especially in cases of:

- Aesthetic reconstructions in the anterior region, especially in patients with a thin gingival biotype
- Gingival recessions where a white coloured implant is a great advantage
- For patients with a proven titanium allergy
- For patients who prefer a bio-holistic/metal-free dental approach, excluding corrosion and conduction of temperature or radiation via metals.

Having reviewed the above, further research is certainly required to enrich our understanding of the different materials and its applications. Three themes in particular need to be explored:

- How 'undesirable' is the use of titanium as a dental implant material for general health
- What is the correlation between the corrosion of titanium and the development of peri-implantitis
- What are the long-term clinical results of zirconia as an implant material? **IDT**

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