

A review of contemporary materials in implantology

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“Many clinicians only recognise two types of Titanium implant biomaterials: commercially pure (cp) titanium and titanium alloy. However, there are six distinct materials which include four grades of cp titanium and two Ti alloys...”

Osseointegration is defined as the “direct anchorage of an implant by the formation of bony tissue around an implant without the growth of fibrous tissues at the bone implant interface at the light microscope level”. Implantology has grown from the discovery by Professor Per-Ingvar Brånemark in the 1950’s that titanium was able to integrate to bone (Figure 1). Titanium and its alloys are frequently used in dentistry, primarily due to its excellent biocompatibility and high corrosion resistance; good mechanical properties; and low thermal conductivity.

Many clinicians only recognise two types of Ti implant biomaterials: commercially pure (cp) titanium and titanium alloy. However, there are six distinct materials which include four grades of cp titanium and two Ti alloys. Stainless steel has been used as bone plates and screws and although stronger, cheaper and easier to machine, its corrosion properties are inferior to Ti and so this material is not approved as a dental implant material.

Physical and mechanical properties

The anchorage of implants is dependent on the mechanical retention or ankylosis created by the closeness of the bone to the implant surface. The implant material must have a high yield strength,



Figure 1. Implant surface undergoing osseointegration process with remodelling of bone.

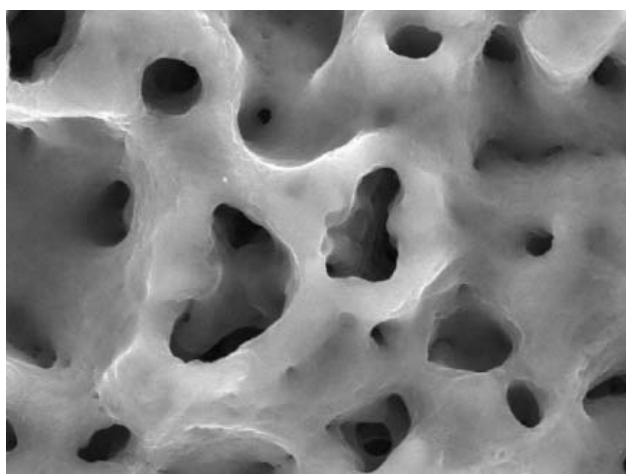


Figure 2. Nobel Biocare's TiUnite surface (x5000).

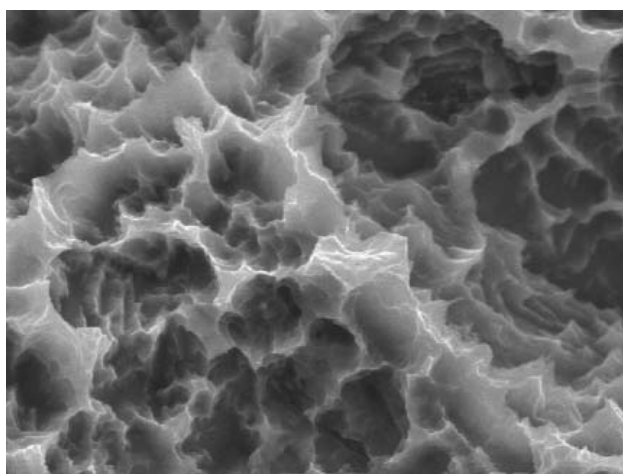


Figure 3: The Straumann SLA surface (5000x).

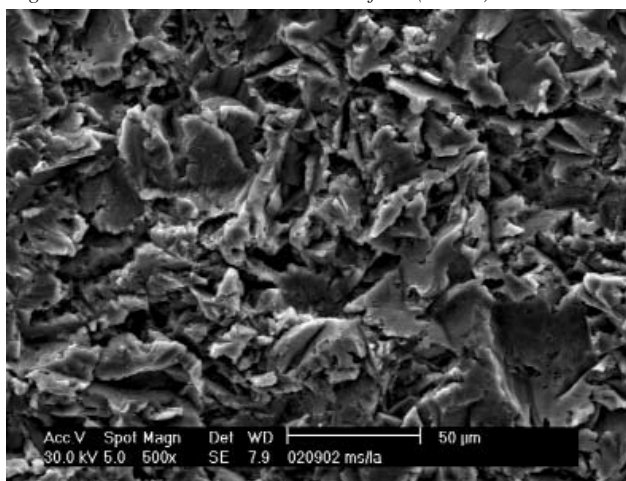


Figure 4. AstraTech's Osseospeed surface.

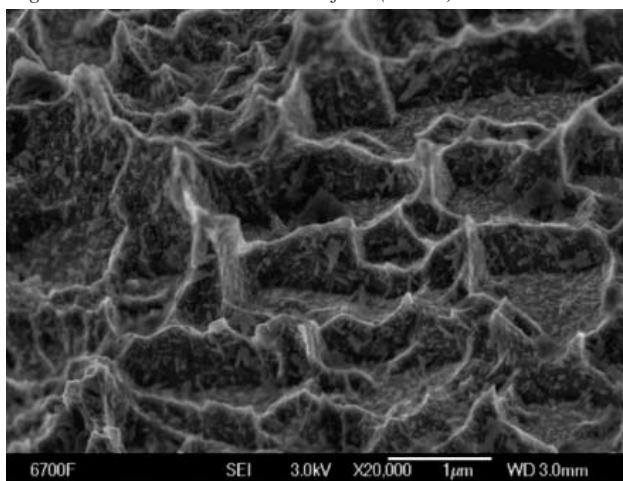


Figure 5. Biomet 3i's Nanotite surface.

which basically describes the ability of the implant to bear loads without buckling or undergoing excessive permanent deformation. This yield strength also determines the ability to prevent failure due to distortion under occlusal and other forces.

A high modulus of elasticity or stiffness is needed for the implant to distribute forces to the surrounding bone tissue. Implants must also present with high fracture toughness or the ability to resist fracture in the presence of flaws of damage to the surface.

All six of the commercially available dental implant biomaterials (Table 1) have good biocompatibility, tissue response and predictability. None have proven to be more biocompatible than another. Some, however, are stronger than others and if a patient has a history of parafunction or

implant fracture then the clinician may prefer to use an implant made of titanium alloy, rather than the weaker cp Grade 1 Titanium. In addition, small diameter implants or implants with thin walls may indicate the need for higher strength materials like cp Ti grade 4 or a Ti alloy.

Materials used by the most popular manufacturers are:

- NobelBiocare: commercially pure Titanium - cold worked variant of Grade 4 Titanium for all TiUnite implants. This has a tensile strength of 860 MPa, (higher than conventional Grade 4 Titanium and has similar strength to that of Titanium alloy).
- Straumann: commercially pure Grade 4 Titanium.
- AstraTech: commercially pure Grade 4 Titanium.
- 3i: Titanium alloy.

Biocompatibility

The implant material should be biocompatible and for metallic materials, a high resistance to corrosion in vivo promotes biocompatibility. However, no matter how corrosion resistant a metal is, ions from the implant can leach into the body's tissues and these ions have a low intrinsic toxicity to living tissues.

Corrosive behaviour

Corrosion leads to release of compounds into the biological environment, which may then cause adverse effects, such as toxic or allergic reactions. Corrosion resistance is a prerequisite to biocompatibility.

Titanium and its alloy Ti-V-Al are reactive metals with the titanium oxidising in the presence of oxygen to form titanium oxide (TiO₂). This oxide layer is stable with a thickness of approximately 10 nm

and contributes to its electrochemical passivity. This layer separates the reactive Ti from electrolytes, which gives it corrosion resistance. So Titanium with an intact layer of titanium oxide is very corrosion resistant, but can be corrosive under mechanical stress or, there is a deficiency of oxygen or at low pH level.

Fluoride has a high affinity to Titanium, as it can infiltrate and dissolve the stabilising oxide layer. This means that oxidised Ti is “reactivated” by electrolytes, which contain fluoride ions. Specifically, caries-preventive fluoride gels increase the fluoride corrosion and surface roughness of Titanium due to their pronounced adhesion. The fluoride gels with low pH can cause corrosion after only a few minutes and Lenz (1997) observed that fluoride gels should not be used on patients with titanium and its alloys. It is the combination of low pH and fluoride that cause corrosion, with even low concentration of fluorides not causing any relevant corrosion at a neutral pH level.

There is also the use of fluoridated bleaching gels in dentistry, which may cause damage to patients with implants and this needs further research.

Interactions with microorganisms

Titanium oxide with the high electrostatic binding capacity of the passivating layer combined with the roughness of surface can result in rapid bacterial colonisation (Yoshinari et al; 2000, Kronstrom et al; 2000). Consequently, plaque can accumulate on titanium like natural tooth structures and the bacteria are similar to strep. Sanguis, initially colonising the surface followed by adherence of other bacteria.

Toxicity

There have been contradictory reports about toxic effects of Ti and its alloys. Studies by Tomakidi et al (1999) and Guertsen (2002) using cell culture studies revealed no cytotoxic or genotoxic effects due to titanium corrosion products. It has been found that small titanium particles can be generated due to wear inducing programmed cell death or apoptosis in mesenchymal stem cells (Kumazawa et al; 2000, Wang et al; 2002).

No growth inhibiting effects in cell cultures were caused by nickel-titanium alloys (Rose et al, 1998), however Titanium–aluminium–vanadium alloys alter intra-cellular enzyme concentration

Table 1. Mechanical properties of implant biomaterials

Material	Modulus (GPa)	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	Density (g/cc)
Cp Grade 1 Titanium	102	240	170	4.5
Cp Grade 2 Titanium	102	345	275	4.5
Cp Grade 3 Titanium	102	450	380	4.5
Cp Grade 4 Titanium	104	550	483	4.5
Ti – 6Al – 4V	113	860	795	4.4
Co-Cr-Mo	240	700	450	8.5
Dentine	18.3	52	n/a	2.2
Enamel	84	10	n/a	3
Cortical Bone	18	140	n/a	0.7

Mechanical properties of different materials (modified from McCracken M. Dental Implant Materials: Commercially pure titanium and titanium alloys. J Prosthodont 1999;8(1):40-43).

(Siebert et al, 1989). In addition, use of this alloy has been questioned due to the possible toxic effects of aluminium and vanadium. Siebert (1989), in experimental long-term studies in mice did, not find any adverse tissue reactions.

The available data indicate that cp Ti and its alloys are biocompatible. Cytotoxic reaction in tissues adjacent to Ti restorations may be caused by small Ti particles, generated by wear or other abrasive processes.

Allergic reactions

Titanium is frequently used as an alternative for patients with metal allergies, as there are minimal allergic sufferers. Sensitivity to Ti has been described and Schweitzer reported the first case of a titanium allergy in dental literature in 1997. Other reports have been non-dental, frequently with heart pacemakers.

Biostability

Previous reports describe greyish discolourations in the vicinity of titanium implants. These were identified as local Titanium discolourations. Other researchers have found discolouration around Ti₆Al₄V hip implants due to Ti necrosis (Black et al, 1990). Hillman and Donath (1991) found that macrophages and foreign body cells identify Ti as foreign body and the cells phagocytose small metal particles from Ti surfaces.

Surface preparation and treatment

There have been recent developments in the treatment of the surfaces whereby there can be modified or additive procedures done to improve osteoconduction. These features have enabled higher bone to implant contact, faster healing times with greater initial stability and interestingly, there is now evidence to support a soft tissue interaction that may be beneficial.

Proprietary surfaces include:

- Tiunite (NobelBiocare) - a porous titanium oxide implant surface manufactured through an anodic oxidation process. The process induces the oxide layer to grow and renders a porous surface structure. The pores are 1 to 7 µm in diameter and volcano like elevations 1-4 µm high (Figure 2).
- SLActive (Straumann) - Introduced in 2005, this surface is claimed to be the first chemically active implant surface. This is a sandblasted, large grit, acid etched surface that is rinsed with water and stored in an isotonic sodium chloride solution. It is claimed that this allows the surface to be hydrophilic and allows greater wettability. This surface has a maximum peak to valley height of 1.16 microns (Figure 3).
- AstraTech (Osseospeed) is a micro-roughened titanium surface. It is similar to the TiOblast surface (blasted with Titanium Dioxide) and chemically modified by treating with hydrofluoric acid leaving fluoride on the surface (Figure 4).

- Zimmer:
 - HA coated - HA is applied through a thermal plasma spray;
 - MTX - use of HA to grit blast the implants to create greater surface area;
 - MP-1 - uses both HA (middle) and MTX (coronal and apex) surfaces on different sections of the implant.
- 3i (Osseotite) is a dual acid etched surface consisting of 1-3 micron peak to peak and 5-10 micron peak to valley characteristics.
- 3i (Nanotite) - this surface is achieved by depositing nanoscale amorphous crystals of calcium phosphate onto the Osseotite surface which increases the surface topography (Figure 5).
- Additive surfaces like hydroxyapatite have also been used to improve osteoconduction. There is concern regarding the enhanced bacterial susceptibility of the hydroxyapatite coatings compared to Titanium and also the possible failure of the hydroxyapatite coatings as a result of hydroxyapatite fracture.

There is also research into using bone morphogenic (BMP) proteins at the tissue-implant interface to accelerate and enhance bone formation and development around implants and in graft situations.

Conclusion

Titanium exhibits excellent biocompatibility, corrosion resistance, a high strength to weight ratio and reasonable machinability. Titanium and its alloys have good physical and mechanical properties with high yield strength and fracture toughness suitable for implantology. There is variation in the strength with alloys and different grades being stronger

(IV>I) which may be required for narrow diameter implants and for bruxists.

There is data to indicate that there are adverse effects to Ti and its alloys, but these are rare and are considerably less than that produced by other metals. It is likely that non-metallic materials, specifically ceramics, will eventually replace pure metals and alloys e.g. zirconium implant materials, and ongoing research and clinical trials are underway.

The majority of implant manufacturers have modified the surface of implants compared to the traditional machined surfaces. This is achieved by roughening the surface by different means including sand blasting, acid etching, additive coatings, electrolytic oxidation with the aim of enabling higher bone to implant contact and faster healing times with greater initial stability. These modifications have allowed continuing high success rates over the years, however the link between peri-implantitis and roughness of implant surfaces will need to be further investigated with some researchers reporting that this may become a problem once these surfaces are exposed.

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About the author

Dr Christopher Ho graduated in Dentistry with First Class Honours at the University of Sydney and completed postgraduate studies in the Graduate Diploma in Clinical Dentistry in Oral Implants. Dr Ho is a regularly invited lecturer on aesthetic and implant dentistry within Australia and internationally. He has been trained in multiple implant systems, including the Branemark, Nobel Replace, and Nobel Active systems. His postgraduate implant education has been through the University of Sydney, where he received his postgraduate diploma and he has attended courses at the UCLA College of Dentistry. He is involved with all aspects of implant treatment performing both surgical and prosthodontic phases of treatment.