Use of CP Titanium and Titanium alloys for Dental Implants
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Abstract
Professor Per Ingvar Branemark of Sweden published his results on 15 years of research in 1980 and started the modern era of dental implants. The implants he used at the time were CP Grade 1 Titanium screws with a machined surface. The implants were used to restore the edentulous patient with a full-arch screw retained prosthesis. Since that time dental implant treatment has become commonplace and expanded to include single tooth restorations, immediate placement in fresh extraction sites and immediate loading of implants after they have been inserted into the jaw.

Dental implants, screws and abutments are predominantly made from CP Titanium or Titanium alloy. These materials are selected for their strength and proven biocompatibility.

Extremely high functional loads are placed on dental implants during chewing. To deal with these loads, implant designers have turned to high strength CP Titanium grades with yield strengths up to 109 KSI as the material of choice. Abutment screws are typically made from Ti 6Al 4V ELI and may be treated with low friction coatings to obtain high clamping forces.

Introduction
In the 1960’s and 1970’s dental implantology was a cottage industry in which dentists were primarily the creators of various implant designs, who then created small companies to bring these products to market. In 1980 Professor Per Invar Branemark, an orthopaedic surgeon in Sweden, published his 15 year clinical results using Cp Grade 1 screw shaped dental implants with a machined surface to support full-arch screw-retained dental restorations. Professor Branemark established new specifications for implant surfaces and designs and showed that careful surgical placement of these screw shaped implants into the edentulous jaw resulted in the ability to maintain a long term functional load. He called this concept osseointegration and his techniques ushered in the modern era of dental implantology.

Material Strengths
Today’s dental implants are manufactured in a wide variety of shapes, abutment connections and surface finishes. The predominant designs are two-piece screw shaped devises with a connection at the top to accept a transgingival abutment. The dental implant assembly consists of three components; the dental implant, which is screwed into the bone, the transgingival restorative abutment and the abutment screw, which attaches the abutment to the implant. Dental restorations can be retained to the abutment with dental cements or with a secondary retaining screw.

Dental implants must be designed to withstand very high masticatory forces. To resist the high bending moments produced by these masticatory forces, the dental implants can be made from Ti 6Al 4V ELI Titanium alloy, but are most commonly made from Cp Grade 4 Titanium with yield strengths as high as 109 Ksi. Materials with this strength allow the design engineer to design two-piece implants as narrow as Ø3.25 mm and one-piece implants as narrow as Ø3.0 mm.
The restorative abutments and abutment screws are most commonly made from Ti 6Al 4V ELI Titanium alloy. A popular method of indexing the abutment to the implant is with a three lobe boss on the abutment, fitting into a three lobe shaped pocket formed into the implant upper surface. The abutments are clamped to the implants with the abutment screws, usually tightened to 35 Ncm torque utilizing specially designed torque wrenches. For this type of implant to abutment connection to be effective, it is essential to achieve a clamping force high enough to resist the high masticatory forces and prevent the abutment screw from loosening.

One drawback of using titanium alloy abutment screws is the very high coefficient of friction between the screw head and abutment and at the threads in the implant. This friction limits the amount of preload attainable in the abutment screw to approximately 30% of the yield strength of the screw. This amount of preload is insufficient and can result in problematic screw loosening. High strength Gold alloy screws can be used instead of Titanium alloy with excellent results, but with the drawback of high material cost. To solve this, Noble Biocare engineers developed Torqtíte™ Titanium alloy abutment screws with special low friction coatings such as Tiodize and amorphous diamond like coatings. These abutment screws are able to achieve preloads 75% to 100% higher than uncoated screws.

Dental implants are permanently implanted into the patients jaw and are expected to last the life of the patient. Fatigue resistance is therefore of paramount importance as a fractured implant is very debilitating to the patient, often requiring a year or more of treatment to correct. A fractured implant is time consuming and expensive for the clinician to treat as well.

In 1992 engineers from three implant companies jointly developed a standardized 30° off axis fatigue test to evaluate existing and new implant/abutment designs. From this testing a baseline endurance strength of 290 N @ 5 million cycles was established. This is the minimum strength deemed acceptable for narrow Ø3.25 mm diameter implants used in the anterior region of the mouth. The popularly used NobelReplace Ø4.3 mm implants from Nobel Biocare have endurance strengths of 445 N. Today we have 14 years of very favorable real time data to compare to these fatigue strength data and have a high confidence level when developing new designs based on this criteria.

Surfaces
In the 1980’s additional surface treatments, such as Titanium plasma spray and acid etching, were developed to increase surface area and enhance the mechanical fixation of the implants into the bone. In 1984, hydroxylapatite coated implants were introduced, which formed a chemical bond to the bone and were shown to be osseoconductive.

Today, Titanium plasma spray implants have become obsolete and hydroxylapatite coated implants are rapidly headed in this direction. These surfaces have been replaced with various forms of grit blasting, grit blasting followed by acid etching, acid etching only, and anodic oxidation. Unique to the industry, the Nobel Biocare TiUnite™ surface is produced through anodic oxidation in a phosphoric acid solution. This results in a porous Titanium Oxide layer approximately 10 µm thick, which demonstrates the same type of osseoconductive properties as hydroxyalapatite. The TiUnite surface was created with the intention that it act as a delivery vehicle for the bone morphogenic protein rhBMP-2, which will give the implants osseointductive capabilities. The first human clinical studies with rhBMP-2 on dental implants are currently underway.
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Use of Cp Titanium and Titanium Alloy for Dental Implants

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High Strength Cp4 Titanium

Yield strength
• 109 ksi

Benefits
• Thin sections
• Small diameter implants
NobelReplace™
Tapered Implant
Esthetic Abutment
Torqtite® Abutment Screw

Material: Ti 6Al 4V

Surface: Tiodize and amorphous diamond coatings

Preload: 75% - 100% increase
Fatigue Test Set-up
Machined

Titanium Plasma Spray

Hydroxylapatite Plasma Spray

Acid Etched
TiUnite™
A Titanium Oxide Surface

• Growth of native TiO$_2$ layer
• Anodic oxidation

• $\sim 150 \text{ Å} \rightarrow \sim 10 \mu\text{m}$
• $10,000 \text{ Å} = 1 \mu\text{m}$
Machined

TiUnite™

Apposition

Osseoconduction

Bone healing after three weeks in rabbit femur

Schüpbach
Osseoconduction:

Bone formed directly on the implant surface and growing out from existing bone, along the implant surface

TiUnite™ exhibits highly osseoconductive bone growth up to 50 µm per day

Schüpbach
Pre-osteoblasts

The only cells able to migrate on an implant surface. They use the open pores to attach and to migrate on the surface by using pseudopodia.

Schüpbach
Pseudopodia attached to TiUnite™ pore

Schüpbach
TiUnite™

Pre-osteoblasts develop into osteoblasts

Schüpbach
Osteoblasts develop into bone cells

Schüpbach
Osseointegration characterized by anchorage of bone in the open pores

Schüpbach
Groovy Implants
Schüpbach
TiUnite™/rhBMP-2
Teeth in an Hour™
Virtual Planning
Planning Result
To PROCERA
Dental technician delivers prosthesis and drill guide
2 Days after Surgery
Thank you