POROUS TANTALUM TRABECULAR METAL: A Systematic Review

Type of Study: Systematic review
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[1]Kirtana Gopalasamy, [2]Dinesh Prabu

[1]Student, [2]Senior Lecturer
Department of Oral and Maxillofacial Surgery
Saveetha Dental College and Hospitals,
Saveetha Institute of Medical and Technical Sciences,
Saveetha University
Chennai 600077, Tamil Nadu, India.

Corresponding Author
Dinesh Prabu
Senior Lecturer, Department of Oral and Maxillofacial Surgery
Saveetha Dental College and Hospitals,
Saveetha Institute of Medical and Technical Sciences,
Saveetha University
Chennai 600077, Tamil Nadu, India

Abstract

Aim: To conduct a systematic review on porous tantalum titanium implants

Objective: To conduct a systematic review on porous tantalum trabecular metal implants in order to summarise the concept and applications of newer dental implant technology trabecular implants in implant dentistry

Background: porous tantalum trabecular metal has been recently used in dental implant technology along with titanium implants as a new form of implants surface and bone integration and enhancement. However there is very little information present on the applications of implant dentistry.
The porous tantalum three-dimensional enhancement of titanium dental implant surface allows for combining bone ongrowth together with bone ingrowth, or osseo incorporation. While little is known about the biological aspect of the porous tantalum in the oral cavity, there seems to be several possible advantages of this implant design

Reason: This systematic review is mainly done to create awareness on porous tantalum trabecular metal technology being used in implant dentistry and its improved osseointegration.

Keywords: immediate loading, implant, implant design, implant surface, osseointegration, surface properties

INTRODUCTION

Over the years the number of edentulous people and the number of missing teeth has increased many folds and is even worse in the developing world. Edentulism is a precursor to various systemic and oral diseases such as osteoporosis, hypertension, diabetes etc. Due to edentulism many biological changes occur which is the loss of masticatory efficiency as when compared to a dentulous patient , there is also reported neural and physiological sensation .Attempts to replace missing teeth with implanted materials have been observed in ancient human remains (Ring, 1995b) , and documented experimentally and clinically in the dental literature since the 19th century (GREENFIELD and E, 1913; Ring, 1995a) . Various treatment modalities have been practiced to treat edentulism which aim at improving function and esthetics for patients. Over the past 3 decades, dental implant systems have been commercialized in a variety of materials, including tantalum (Grundschober *et al.*, 1980; Linkow and Rinaldi, 1988; Ring, 1995b), vitreous carbon (Grenoble and Voss, 1975, 1977; Lemons, 1975), single-crystal sapphire (Kawahara, Hirabayashi and Shikita, 1980; Arvidson *et al.*, 1991), stainless stee (GREENFIELD and E, 1913; Ring, 1995b), titanium (GREENFIELD and E, 1913; Adell *et al.*, 1981, 1990) and other substances.Recently, there has been an incorporation of porous tantalum (Ta) metal into titanium dental implants. This has been an advancement in dental implants which concentrate at improving dental implant therapy in certain populations. This article aims to review the production of tantalum and its testing in canine models and various clinical trials, advantages and cautions, as well as possible clinical applications of the new Ta metal implants.

FIRST USE OF TITANIUM AND TRABECULAR IMPLANTS

The first surgical use of titanium was done in 1940, orthopedic surgeons (BOTHE and T, 1940) first experimented with the surgical use of titanium and reported its extreme biocompatibility

In 1950 following the previous attempts, other orthopaedic surgeons (Leventhal, 1951; Clarke and Hickman, 1953; Brunski, 1988) tested, reported and documented titanium's superior ability to withstand corrosion and remain relatively inert in the body (Williams, 1977; Brunski, 1988; Clark, 1991).

In 1977 orthopedic surgeon Per-Ingvar Brånemark and colleagues (Adell *et al.*, 1981, 1990) published results of their monumental 10-year dental implant study. The Brånemark team documented the processes and conditions in which ordered, living bone could form a direct structural and functional connection with a load-carrying titanium dental implant. The researchers coined the term "osseointegration" to describe the natural phenomenon first reported more than three decades earlier by their predecessors (BOTHE and T, 1940; Leventhal, 1951; Clarke and Hickman, 1953; Adell *et al.*, 1990).

TANTALUM

Ta is a rare, high corrosion-resistant transitional metal element with atomic number 73. The word tantalum was coined from Tantalus, based on a Greek mythology figure. When tantalum was punished to stand in a pool and water under a tree with low hanging fruit and when he reached for the fruit the branch would move higher while he moved to the water the water in the pool would recede . This property of Ta was first noticed by early chemists when Ta was immersed in acids (Greenwood and Earnshaw, 2012). Ta, they found, was highly unreactive in almost all acids, except hydrofluoric acid and acids containing fluoride and sulfur trioxide. Ta is a member of the refractory metals group, which are widely used as components in alloys.Tantalum was found in its oxide form –as columbium, which is a combination of columbite and tantalite (Griffith and Morris, 2003).
Tantalum This highly biocompatible (Avila *et al.*, 2007; Javed and Romanos, 2010; Dos Santos, Elias and Cavalcanti Lima, 2011) metal has been widely used for over half a century in implanted medical devices for humans: dental implants (Schroeder *et al.*, 1981; Brentel *et al.*, 2006; Liu *et al.*, 2007), orthopedic implants (Matsuno *et al.*, 2001; Bencharit *et al.*, 2014), surgical ligation clips (Trisi *et al.*, 2009; Javed and Romanos, 2010), plates, nets and wires used in neurosurgery, cranioplasty, and oral and maxillofacial reconstructions (Romanos, 2009; World Medical Association, 2013), electrodes for pacemakers (Romanos, 2009) and many other clinical applications.

INDUSTRIAL MINING AND PURIFICATION OF TANTALUM

Ta is often extracted from the mineral, tantalite. Industrial mining of tantalum is primarily mined in Western Australia and is also produced as a byproduct of tin Mining in Thailand, China, Ethiopia .Extraction of Ta from naturally occurring tantalite is accomplished by gravity separation, which separates components of the mixture based on the differences of their specific weights. The gravity separation of the components is followed by chemical separation using hydrofluoric acid and sulphuric acid. This chemical separation will extract the oxides of TA from its natural cohabitant element, niobium (Agulyansky, 2004). This is followed by the liquid extraction of the fluorides with the help of organic solvents or potassium fluoride. Recycling Ta is very important. Ta is extremely inert and resistant to acid corrosion. Only hydrofluoric acid and acid solutions containing fluoride and sulfur trioxide can dissolve Ta this inertness is ideal for fabrication of orthopedic implants (Levine *et al.*, 2006). The inertness and biocompatibility of Ta is a result of Ta oxides forming on the surface of Ta similar to titanium and its oxides. Similar to titanium, Ta is very reactive to oxygen and the oxide layer of Ta can form on the metal surface immediately after the surface is exposed to oxygen. Since tantalum being extremely reactive to oxygen soldering and welding is only done in an inert gas environment (Köck and Paschen, 1989).

PRODUCTION OF POROUS TANTALUM TRABECULAR METAL (PTTM)

The most commonly used orthopaedic implants are cobalt chromium, titanium alloys, and stainless steel. Even though they have been widely used they o have their own drawbacks such as volumetric porosity, relatively high modulus of elasticity and low frictional characteristics (Levine *et al.*, 2006). The development of porous Ta metal has allowed for stronger, more biocompatible orthopedic, craniofacial, and dental implants. The structure of porous Ta metal affords a high volumetric porosity, a low modulus of elasticity, and relatively high frictional characteristics.

Even after possessing characteristics such biocompatibility and highly inert which are ideal for an orthopaedic implant, tantalums use was limited because of the difficulty in manipulating solid Ta. Replacing osseous structure traditionally uses solid materials such as titanium or porous materials such as hydroxyapatite (HA) or tricalcium phosphate (TCP).

It was not until the early 1990s that PTTM was introduced (Kaplan, 1994). PTTM, known commercially as Trabecular Metal Material (Zimmer, Trabecular Metal Technology, Inc., Parsippany, NJ, USA) is an open-cell porous biomaterial with a structure similar to trabecular bone by having three-dimensional dodecahedron repeats. The open-cell dodecahedron repeats are fabricated by a foam-like vitreous carbon scaffold (Kaplan, 1994; Cohen, 2002), which forms an initial general scaffold and eventually becomes the internal skeleton of the PTTM implant device.

Ta coating is done with the help of chemical vapor diffusion process using hydrogen and chlorine gases. The Ta is evaporated as TaCl2, and the Ta molecules are then deposited onto the scaffold (Zardiackas *et al.*, 2001; Cohen, 2002). PTTM is, therefore, superior to other metal implant technologies such as titanium because it has a high degree of porosity.
The PTTM allows an implant surface enhancement not only for bone ongrowth but also bone ingrowth. PTTM structure allows neovascularization and new bone formation directly into the implant. This concept is known as "osseo incorporation (Bobyn *et al.*, 1999; Cohen, 2002).

PTTM-ENHANCED TITANIUM DENTAL IMPLANTS

PTTM implants have been seen to have great success in the orthopedic field for almost two decades, the technology has not been applied to dental implants until recently. Ever Since the introduction of the osseointegration theory , there have been two distinct changes on internal connection and implant surface designs to that of which Branemark used .All of the implant surface designs in the current implant dentistry have some features that increase surface roughness in order to obtain a larger and more stable osseointegrated bone-implant contact area. Improving the roughness of the implant surface has shown to reduce the peri-implant bone loss.surface roughness technologies often improve the surface contact in the micro-and nano-level by reducing the free-energy of the surface and thereby facilitating the adsorption of platelets, monocytes, and clotting proteins (Zardiackas *et al.*, 2001). Reducing the free-energy of the surface promotes the adherence of platelets that when adsorbed release platelet-derived growth factors, which are chemotactic and mitogenic for mesenchymal cells and osteoblast progenitor cells. This serves to draw cells toward the implant surface this facilitates in attracting osteoprogenitor cells and facilitates rapid angiogenesis and osseous regeneration.

PTTM technology was introduced to create a three-dimensional bone ingrowth scaffold around dental implants. Trabecular PTTM metal was added to the middle section of the titanium dental implant. The apical and cervical sections of this PTTM-enhanced titanium dental implant retain the screw-type design with a rough surface created by grit blasting with HA Particles. Both the components of the implant such as the titanium alloy and the PTTM metal are manufactured separately .The PTTM sleeve, ~2 mm cylinder,is composed of 2%vitreous carbon core scaffold and 98% Ta coating. The PTTM sleeve is then placed into the middle titanium alloy core, and the core is then laser welded to the apical portion (Mendonça *et al.*, 2008).

Mechanical integrity between Trabecular Metal Material and a single-tooth implant

Dillion et al.38 conducted a mechanical experiment to determine the ability of a 3-dimensional Trabecular Metal Material bone graft to support an implant-supported, single-tooth restoration.No failure of the Trabecular Metal Material or at the interface was detected.38 All samples failed due to deformation of the abutment screw.Both single cycle and fatigue tests indicated that the implant/Trabecular Metal Material system was able to withstand loads that were significantly greater than those found in vivo (Parikh, 2002).

Mechanical feasibility study on the potential use of Trabecular Metal Technology as a dental implant material

Trabecular Metal Material blocks showed good initial stability and were strong enough to resist compressive loading forces that exceeded those documented for the oral environment.

Insertion torque analysis of Zimmer Trabecular Metal Dental Implants in simulated dense bone

Trabecular Metal Dental Implants exhibited insertion torque values within the range exhibited by the commercially available control implants. Numerous studies (Ostman, Hellman and Sennerby, 2005; Achilli, Tura and Euwe, 2007; Neugebauer *et al.*, 2009; Vidal *et al.*, 2011) have used insertion torque values as stability guidelines for determining whether a dental implant can sustain immediate loading, although there is no clinical consensus on what should constitute a minimum insertion torque level.The average insertion torque values of Trabecular Metal Material test implants in this study conducted by (Zimmer et al) thus significantly exceeded this threshold.Insertion and removal torque testing in bone revealed no structural compromise to the implant or its porous section.

Mechanical Testing:

Trabecular Metal Dental Implants subjected to cyclic loading and compression bending resisted fatigue fracture and deformation and surpassed strength requirements for normal loading conditions in the posterior human jaw.Implant stability tests showed that the dental implant design was able to achieve adequate mechanical stabilization for immediate loading in selected patients using both standard (hard bone) and osteo compressive (soft bone) surgical protocols (Parikh, 2002; Bencharit *et al.*, 2014).

From the mechanical testing done, it was noticed that:

1. Trabecular Metal Dental Implants achieve insertion torque levels comparable to Tapered Screw-Vent and NobelReplace®
2. Trabecular Metal Dental Implant did not corrode in Ringer's solution.
3. Trabecular Metal Dental Implant was not altered by production cleaning methods.
4. Higher assembly forces did not impact fatigue performance of Trabecular Metal Dental Implants.

5. Trabecular Metal Dental Implants 4.1mm in diameter exhibited endurance levels under insertion torque and cyclic loading that were mechanically adequate for immediate loading

Animal studies

In a study conducted by National institute of health in 2000 (Aw *et al.*, 2012), it was conducted to evaluate the bone in growth and outgrowth turnover (osseoincorpration) in Trabecular metal implants for the treatment of surgically created mandibular defects in canines. It was found that After 6 months of healing, all 4 surviving samples had developed osteoid crossing through the Trabecular Metal Material, and 3 out of 4 samples had mineralized bone in the center of the material.

In another study conducted by Ohio state university in canine models , for the evaluation of trabecular metal dental implants in dogs, in the study 24 trabecular metal Implants and 24 Screw-vent were randomly placed in healed mandibular premolar locations of eight dogs.Histomorphological analysis were performed on two dog mandibles at two, four, eight and twelve weeks. It was noticed that new bone was forming inside Trabecular Metal Material pores in two weeks. New bone growth was evident in Trabecular Metal Material at every assessment period.

Human Clinical studies:

In 2010, Zimmer Dental began two international, prospective human clinical studies of Trabecular Metal Dental Implants. The first, a proof-of principle pilot study, is evaluating the use of Trabecular Metal Dental Implants for immediate loading. The second study is a Longitudinal Data Collection Program that is prospectively gathering data on the placement and functioning of Trabecular Metal Dental Implants in routine clinical practices.

In a study conducted by (Materia, no date; Bencharit *et al.*, 2014) in 2013 he noticed that Early clinical findings indicated that immediate loading of PTTM implants was safe and effective under the controlled study conditions.

In a randomized clinical trial, Tan and colleagues (Tan *et al.*, 2011) reported that implant collars with 1 mm of microtextured surface maintained significantly higher bone levels than implant collars without microtextured surfaces. In another randomized clinical study, den Hartog and colleagues (den Hartog *et al.*, 2011) reported that implants with microgrooves preserved significantly more crestal bone than implants with machined surfaces. In a systematic review of the literature, however, Bateli and Strub (Bateli, Att and Strub, 2011)found that the current literature provides insufficient evidence about the effectiveness of different implant neck configurations in the preservation of marginal bone. The authors (Bateli, Att and Strub, 2011) concluded that more long-term randomized controlled studies are needed to elucidate the effects of such modifications.

ADVANTAGES OF PTTM-ENHANCED TITANIUM DENTAL IMPLANTS

The PTTM-enhanced titanium dental implants theoretically provide several advantages over other implant designs. The PTTM portion of the implant has an open-cell dodecahedron repeat structure that allows for rapid endothelial budding and ingrowth. This allows for rapid endothelial neovascularization that is critical to permit subsequent osteoblast precursor recruitment and osteoblastic cell differentiation, growth,and matrix secretion (Hacking *et al.*, 2000). This healing healing granulation tissue helps with new tissue formation and bone ingrowth thereby helping with immediate and early loading in orthopedic implants (Miyaza *et al.*, 2002). While titanium allows faster cell proliferation, Ta enhances osteoblastic differentiation process (Stiehler *et al.*, 2008).

The trabecular structure of the porous Ta metal in PTTM enhanced titanium dental implants can also improve osseointegration simply by increasing bone-implant interface area in the three-dimensional manner promoting angiogenesis and mimicking natural osseous structure (Miyaza *et al.*, 2002).

The added advantage of trabecular formation of PTTM helps with the elastic modulus being similar to the bone , mechanically superior to other alloys used in dental implants (Miyaza *et al.*, 2002). PTTM allows for elastic deformation and load distribution. This helps with avoiding localised stress at the orthopedic artificial joint. Bone resorption is less likely to be seen since the stress is Evenly distributed throughout the structure and to the surrounding bone.

The advantages of high biocompatibility, similar porous structure to natural bone, andexcellent mechanical properties of PTTM-enhanced titanium dental implants may give them an advantage over other dental implants, particularly for patients through enhancement of osseointegration, or osseo incorporation.

CLINICAL APPLICATIONS OF PTTM ENHANCED TITANIUM DENTAL IMPLANTS

PTTM implants have shown to have a high success rate in the case of poor tissue healing in patients with comorbidities such as diabetes (Moy *et al.*, 2005; Javed and Romanos, 2010), osteoporosis (Roberts *et al.*, 1992), irradiated bone (Taylor and Worthington, 1993; Brogniez *et al.*, 1998), and heavy use of tobacco (Bain and Moy, 1993; Gopalasamy and Dhanraj, 2019).

Secondly this has shown to have positive results when there is insufficient remaining bone structure that requires simultaneous bone augmentation or in the newly grafted bone,PTTM has seen to help in cases that need simultaneous implant placement and horizontal/ vertical bone augmentation or in cases with simultaneous implant placement with sinus augmentation or cases with newly grafted sinuses or sockets.

Thirdly , PTTM implants serve as a valuable alternative for patients with bone quality types 3 and 4. Also in patients with impaired wound healing the improved and enlarged surface area provided by the PTTM collar helps in faster and more robust osseointegration.

Fourthly, PTTM enhanced titanium dental Implants provide a better treatment option for immediate placement and loading of implants.

POTENTIAL COMPLICATIONS WITH PTTM-ENHANCED TITANIUM DENTAL IMPLANTS

Although PTTM implants have been widely used and have been successful in orthopaedic implants . The use in the oral cavity remains limited. The major concern is the uniqueness of the oral environment.Unlike most orthopedic surgical sites, the oral cavity is a complex non sterile field, which harbors over 500 different bacterial species. The interactions of the host tissue, saliva, and microorganisms can make it difficult to predict how PTTM implants would react. The implants are susceptible to complications because of Surface biofilm and compromised immune ability at implant tissue interface .

Since PTTM dental implants are comparatively new to the market the treatment option in case of peri implantitis remains unanswered until there results from London's term studies in these implants. PTTM in the middle third portion and the apical titanium portion may be prone to fracture especially if they are placed in hard bone (type 1) with inappropriate high torque. These implants are however recommended for bones that are relatively soft (type 3 or 4). The fracture of implants during insertion may therefore not be a major issue in soft bone.

CONCLUSION

Development of PTTM-enhanced titanium dental implants combined conventional titanium implant design and instrumentation with PTTM technology. This helps in osseointegration in a three-dimensional manner, which may be a major breakthrough compared with the current focus on titanium implant surface technologies. Based on the studies done of canine models and clinical trials from orthopedic implants as well as dental implants we see that this type of Implants are indicated in poor healing situations also in immediate loading and early loading of implants. There still remains a few unanswered questions such as treatment and management in cases of periimplantitis as PTTM impa,nets are relatively newer to the market . Though the properties of trabecular implant makes it to be an enhanced implant biomaterial prospective longitudinal research studies are required to see the efficient clinical success on a larger scale.

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