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Effects of dental implant corrosion- A Review

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ABSTRACT

Implanted prosthetic devices have become an integral modality in restorative dentistry. The cardinal prerequisite of a biomaterial is that the material and the tissue domain of the physique should coexist without having any unwanted effect on each other. Biological risk associated with ionic particles released from metallic implants are critical and very much sought after. Corrosion of dental implant is a pertinent issue as it is intended to function in human body for a life time. This article gives a systematic review on dental implant corrosion.

1. INTRODUCTION

Implants have become reliable treatment option for missing teeth after Branemark® has been introduced in the market in 1960. Appropriate selection of biomaterial is a key factor for success of implants. The required properties of biomaterial as implant include modulus of elasticity closer to bone (18 GPa), osseointegration, biocompatibility, improved tensile, shear strength, compressive, yield strength, hardness and fatigue strength to prevent fracture along with 8% ductility [(1)]. Stainless steel and titanium were commonly used implant material and zirconia being the recent material of choice [(2)]. There are many different types of titanium obtainable as implant biomaterials according to American Society for Testing and Materials (ASTM) as displayed in Table 1 [(3)].

Corrosion is a progressive deterioration of metals by electrochemical attack when it is subjected to the electrolytic domains provided by the human body [(4)]. Corrosion is of grave concern as metal ions and debris are produced in this process and the aggregation of this may cause detrimental tissue reactions *in vivo* [(5)]

2. TYPES OF CORROSION IN IMPLANT BIOMATERIALS

Corrosion may be general and localized in implant biomaterial. General corrosion observed uniform dissolution of the metal surface and localized corrosion distributed at specific sites on passive metal surface corresponding to high local dissolution [6]. Types of corrosion explained in Table 2. Corrosion in dental implants are relevant as it can lead to roughening of the surface, weakening of the implant, liberation of elements from the metal or alloy, and toxic reactions due to dissolution of alloy components and bone destruction due to current flow due to corrosion [7]. Titanium and titanium alloys are biocompatible owing to the presence of titanium oxide layer [8]. If the passive oxide film is thinner, it is easier to penetrate and resulting in an increase in potential for pitting corrosion [9]. Pitting is the most common type of corrosion occur on the dental implant due to tear down of passivating oxide film which is aggravated by the presence of proteins in the tissue fluid and serum [10]. In pitting, a local anodic point and cathodic point forms a small corrosion cell with the surrounding normal surface [10]. It is a localised form of corrosion. Once a pit has initiated, it grows into a cavity showing a localised appearance. Pits penetrate from the surface downward in a vertical direction [11]. In an experimental study, it was shown that pitting corrosion can occur on titanium surface upon retrieval of surgically placed implants in rats [12]. Pitting corrosion is a localised form of corrosion usually confined to a point or small area takes the cavity form due to breaking down of oxide layer. It is an autocatalytic process due to the formation of local anodic cell and maintained by the spatial separation of the cathodic and anodic half-reactions, which creates a potential gradient and electro migration of aggressive anions into the pit [13]

Corrosive factors in oral environment

Acidic environment, masticatory forces, presence of chlorine and fluoride content play a role in corrosion. Messer et al.(2009) showed an increased corrosion potential for machined titanium implants under inflammation. It is reported that acidic pH related to inflammation can lead to more corrosion for titanium dental implants [16]. Cyclic implant loading from occlusal force in the physiological environment of oral cavity can significantly enhance corrosion rates. An evidence of corrosion by pitting on commercially pure titanium was found after the fluoride ions action [17]. It is been already pointed out that artificial saliva at pH 6.0, 6.5, and 7.5 can led to greater corrosion of the commercial pure titanium discs compared with more acidic saliva [18]. Galvanic corrosion is suggested to occur when saliva penetrates between implants and prosthetic superstructure due to formation of galvanic cell which leads to bone loss. Disintegration of vanadium oxide from the surface of titanium alloy was found to get enhanced in the presence of chlorine [19].

Measurement of corrosion on titanium surface

Impedance spectroscopy at 25 °C proved that Ti6Al4V alloy and titanium have similar corrosion behaviour. But at 37 °C, Ti6Al4V corrosion resistance is decreased due to dissolution of oxide film proving commercially pure titanium is more resistance to corrosion than Ti6Al4V [20]. Probability to get corrosion on implant surfaces were tested among acid

treated, machined, sandblasted and both acid, alumina treated implant surface The implant surface treated with both acid and alumina proven to have more corrosion [21].
Ti13Nb13Zr alloy proved to have higher corrosion resistance than Ti6Al4V[22]. Nanostructured Ti20Nb13Zr proved a promising candidate as implant material when corrosion properties were evaluated using in simulated body fluid using electrochemical impedance spectroscopy analysis. Higher Niobium content contribute higher hardness of titanium alloy and quickly forms passive film. TiNbZr alloy demonstrated superior corrosion resistance compared to titanium, Ti6Al4V, TiMo and TiAlNb alloys[23]. When the implants were coated with hydroxyapatite corrosion resistant was improved compared to untreated implants [24].

3. EFFECTS OF *IN VIVO* METAL LEACHING FROM TITANIUM BASED DENTAL IMPLANTS

Clinical manifestation of corrosion of dental implants can range from soft tissue discoloration to osteolysis [25]. Titanium is a nonessential element as it is not required as cofactor [26]. Corrosion causes release of metal ions to the surrounding hard and soft tissues, lymph nodes, peripheral, and even distant organs. The metal ions may cause staining of the peri-implant tissues and reactions, like perioral stomatitis, osteolysis, oral oedema, and extra-oral manifestations, such as fatigue, hair loss, eczematous rashes, and even episodes of brain-fog have been reported.[27]The addition of titanium ion (Ti) on osteoblast function and the mineralisation of osteoid nodules in rat calvaria cultures was characterised[28] where titanium ions at concentrations of 10 ppm or higher for nearly 24 h were found to be toxic. Normal human serum levels of implant metals are within the following ranges: 1 to 10 ng/ml aluminium, less than 0.01 ng/ml vanadium and less than 4.1 ng/ml titanium [29]. In animal models, titanium was migrated towards cervical region of implant in two months' time without modification of osseointegration.[30] .
Metal ions from corrosion can affect cytokines and thereby osteoblast viability, apoptosis, bone resorbing mediators are influenced. Ti ions adversely affect bone remodelling at the interface of dental implants. Expression of RANKL and OPG mRNAs in osteoblast-like cells is influenced by 9 ppm titanium ion after 24 h of exposure [31]. It is pointed that reduced cellular growth in mediums containing aluminium and vanadium compared to that in free aluminium and free vanadium mediums [32]. This indicated potential cytotoxic effect of aluminium and vanadium for human cells. Based on Manaranche and Hornberger's classification on biocompatibility, class III alloys, including Ti6Al4Vcaused an adverse biological response in patients due the high release of ions [33]. Vanadium ions is considered as a mutagenic agent. Vanadium can cause renal, cardiac dysfunction, hypertension and depressive psychosis [34]. *In vivo* findings of corrosion displayed in Table 3.
The role of implant corrosion products such as metallic ions in periprosthetic osteolysis have been demonstrated in the orthopaedic literature [35]. Seven samples from four human subjects with dental implants were analyzed as test group and six bone samples of similar topographical regions from six human subjects without implants served as control. The contents of various elements in human jawbones were detected by inductively coupled plasma optical emission spectrometry. Ti leaching when assessed in human jaw bone 1940 μg/kg in test group and 634μg/kg in control group. Particles with sizes of 0.5-40 μm were

found in human jawbone marrow tissues. Titanium based alloy implants have showed elevated titanium, aluminium, and vanadium levels in joint replacement cases (with up to 200 ppm of titanium, six times greater than control, 880 ppb of aluminium, and 250 ppb of vanadium). Spleen aluminium levels and liver titanium concentrations were elevated in patients with failed titanium alloy implants [(36)].

The release of aluminium and vanadium due to dissolution of oxide layer has been reported [(44)].Titanium alloy is vulnerable to the oxide changes that are produced by mechanical micro motion [(45)]. This invites concern as significant vanadium leaching from the implants into the blood occurred among female subjects which seeks more attention as vanadium is proven to have carcinogenic and neurotoxic effects [(46)]. Ionic vanadium, aluminium and titanium have mutagenic actions on cells in tissue culture. Toxicity of the Ti-6Al-4V alloy extract in CHO-K1 cells based on the MTT assay and micronucleus assay. The MTT assay indicated that the mitochondrial activity and cell viability of CHO-K1 cells were unaffected by exposure to the extract. However, the micronucleus assay revealed DNA damage and an increase in micronucleus frequency at all of the concentrations tested [(47)]. Toxicity of titanium dioxide when evaluated has been reported in which intraarticular injection of anatase TiO_2 nanoparticles caused follicular lymphoid hyperplasia and inflammatory cells aggregated around the bronchia and in lungs in the TiO_2-exposed synovium, the oxidative damage was induced because the glutathione peroxidase (GSH-Px), reduced glutathione (GSH), oxidized glutathione (GSSG), and superoxide dismutase (SOD) levels [(47)] .
Nanometer titania particles (50 nm) caused morphological changes in neutrophils and decreased the cell survival rate [(48)]. *In vivo* animal testing of Ti6Al4V demonstrated the presence of high levels of aluminium in the bone surrounding the implant [(49)]. It is reported that nanoparticles can pass through the blood-brain barrier (BBB) and may be toxic to the central nervous system (CNS) [(50)]. There is an inverse relationship between particle size and the ability to penetrate the BBB. The testing methods for nanoparticle effect on CNS system have limitations and further studies need to be performed [(42)].

Strategies to improve implant surface

The surface treatment processes to improve surface properties for dental implants can be classified into two categories: surface treatments by subtraction/alterations or modifications of the titanium surface and surface roughening and surface treatments by addition/coatings on the titanium substrate [(51)]. Implant surface can be altered either by physiochemical, morphological, biochemical methods [(52)]. Physio chemical method like glow discharge involves alteration of surface energy, charge to improve bone implant contact. Surface morphology alteration and roughness like sand blasting, acid etching are included in morphological methods. Biochemical methods is a combined method of biology and biochemistry of cellular function and differentiation using adhesion molecules. Arg-Gly-Asp act as mediator of attachment of proteins like osteopontin, sialoprotein, fibronectin.other approach is to coat with osteotropic effect like interleukin, growth factor 1 & 2, platelet growth factor, bone morphogenic protein.

However there is lack of randomised clinical trial to find influence of different surface treated implants on osseointegration and their true differences [53]. Osseointegration of blasted zirconia, calcium phosphate-coated zirconia is still to be evaluated [54]. Even though dissolution of implant coating has been reported in the literature, chemical and structural characterisation of coating thereby comparison between studies were difficult [55].

4. CONCLUSION

Corrosion of dental implant is a pertinent issue. However, there are seldom reports on quantitative assessment of ongoing metal leaching from dental implants. This article put insight into the available literature on dental implant corrosion. They are evidence to support the fact that implant material can undergo corrosion and randomized clinical trials need to be addressing the same as the *in vivo* scenario differs individually.

Clinical significance

Corrosion of dental implant is an indispensable area which invites improvement in biomaterial aspect as the implant restoration are associated with endurance of life expectancy.

Table 1: Implant materials commonly used (ASTM International, 2013)

Commercially pure Ti and Ti Alloy	
Commercially pure Ti	Cp Ti grade I
	Cp Ti grade II
	Cp Ti grade III
	Cp Ti grade IV
Ti-6Al-4V	
Ti-6Al-4V ELI	
Ti-6Al-7Nb	
Ti-5Al-2.5Fe	
Ti-12Mo-6Zr-2Fe	
Ti-15Mo-5Zr-3Al	
Ti-15Mo-2.8Nb-3Al	

Table 2: Types of corrosion

Corrosion	Characteristics
Pitting	▪ Most destructive and common ▪ Happens on surface local pit ▪ Once a pit has initiated, it grows into a “hole” or “cavity ▪ A local anodic point and cathodic point forms a small corrosion cell
Fretting	▪ Caused by the repeated micromotion or friction of a metal component against another material that causes mechanical wear and breaks up the passivating layer on the contact surface of the metallic device

Intergranular	▪ Caused by impurities present at these grain boundaries ▪ Example of intergranular corrosion is carbide precipitation, a chemical reaction that can occur when a metal is subjected to very high temperatures (e.g., 800 °F – 1650 °F)
Galvanic	▪ Degradation of metal when two electrochemically dissimilar metals are in electrical contact in the presence of electrolytic environment ▪ Affected by temperature, hydrogen evolution and surface finish of the metals ▪ If a base metal alloy superstructure is provided over the titanium implant, the less noble metal alloy forms the anode and the more noble titanium alloy is protected as a cathode. NiCrTi is not recommended as superstructures because of leaching Ni ion into the body ▪ It is advised to use Ti/Ti6Al4V and Ti/CoCr instead of noble gold alloys as prosthetic structure (14)
Crevice	▪ Due to difference in the concentration of ions between two areas of a metal like implant screw bone interface ▪ Repassivation is prevented due to low oxygen content
Stress	▪ Due to fatigue of metal
Microbial	▪ As the diameter of microorganisms is less than 10 μm, the prosthetic gaps of 2.5–60 μm can be colonised by several microorganism (15)
Tribocorrosion	▪ Simultaneous action of chemical, mechanical (wear) and electrochemical (corrosion) interactions

Table 3*: In vivo* findings of corrosion

Author	Findings
Jacob et al[37]	Osseointegrated coxofemoral prostheses made from titanium 90% - aluminium 6% - vanadium 4% showed that ions of all three metals pass into the plasma and are excreted in urine
Urban et al [38]	Metal and plastic particles from coxofemoral prostheses and knee replacements in organs such as liver, spleen and lymph nodes
Olmedo et al [39]	Ionic release can cause implant failure due to periimplantitis. Host response that is the phagocytosis by macrophages
Olmedo et al.[40]	Macrophages loaded with metal particles as indicators of the corrosion process in the soft peri-implant tissue of failed human dental implants

Bitar et al [41]	Metal particles from coxofemoral prostheses are ingested by macrophages, stimulating the release of cytokines that contribute to bone reabsorption by activating osteoclasts. In addition to increasing bone reabsorption, these particles can suppress the osteoblast function, reducing bone formation and contributing to osteolysis
Feng et al, 2015[42]	Nanoparticles passed through the blood brain barrier, and neurotoxicity need further evaluation
Guglimotti et al[43]	Metal particles entrapped in the osseointegrated bone tissue and the bone medulla of implants indicating corrosion

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