e - ISSN - 2348 - 2184
Print ISSN - 2348 - 2176

AMERICAN JOURNAL OF BIOLOGICAL AND PHARMACEUTICAL RESEARCH

Journal homepage: www.mcmed.us/journal/ajbpr

A REVIEW ON CORROSION SCENARIO OF BIO IMPLANTS IN HUMAN BODY

Muhammad Idrees [*1] and A.Zechariah Jebakumar[2]

[*1]Dept. of Science, Prince Sultan Military College of Health Sciences, Ministry of Defence and Aviation, Dhahran-31932, Kingdom of Saudi Arabia.
[2]Dept. of Research and Scientific studies, Prince Sultan Military college of Health Sciences, Ministry of Defence and Aviation, Dhahran-31932, Kingdom of Saudi Arabia.

Article Info

Received 30/06/2014
Revised 05/07/2014
Accepted 07/07/2014

Key words :- Corrosion, Biocompatibility, Degradation, Orthopedic Implants, Stainless steel.

ABSTRACT

Biomaterials are used for many devices that can interact with biological system to coexist for longer services with minimum failure. Chemical stability, mechanical behavior and biocompatibility in body fluids and tissues are the basic requirements for successful application of implant materials in human body. Corrosion of metal implants is critical because it can adversely affect the biocompatibility and mechanical integrity. Corrosion is one of the major processes affecting the life and service of biomaterial devices made of metals and alloys used as implants in the body. Corrosion mainly occurs by electrochemical reactions. This paper provides a simple overview on corrosion behavior of various implants and the role of surface oxide film and corrosion products on the failure of implants.

INTRODUCTION

The field of biomaterials is of great importance for the mankind as the very existence and longevity of some of the less fortunate human beings, who even at the time of birth are born with congenital heart disease and also for the aged population who require biomedical implants to increase their life span [2]. Common medical devices made of biomaterials include hip replacements, prosthetic heart valves and the less common neurological prostheses and implanted drug delivery systems. These devices when placed inside the body are termed implants when they are intended to remain there for a substantial period of time, and as prosthesis when they are permanently fixed in the body for long term application till the end of life time [1]. Apart from the diseased people, young and dynamic people like sportspersons often need replacements due to fracture and excessive strain. In addition the increasing traffic has also resulted enormous increase in the number of accidents. This has necessarily led people to opt for orthopedic implants for early and seedy recovery and resumption of their routine activities. The first and foremost requirement for the choice of the biomaterial is its acceptability by the human body. The implanted material should not cause any adverse effects like allergy, inflammation and toxicity either immediately after surgery or under post operative conditions. A bioimplant should have very high corrosion and wear resistance in highly corrosive body environment and varying loading conditions, apart from fatigue strength and fracture toughness [2]. The performance of a biomaterial is determined by its chemical, physical and biological properties [3]. Implant failure refers to the failure of any medical implant to meet the claims of its manufacturer or the health care provider who installs it. Corrosion is one of the major reasons of implant failure.

Corresponding Author

Muhammad Idrees
Email:- iamidrees@hotmail.com

HOW AND WHY IMPLANTS CORRODE

Corrosion, the gradual degradation of materials by electrochemical attack is of great concern particularly when a metallic implant is placed in the hostile electrolytic environment of the human body. The implants face severe corrosion environment which includes blood and other constituents of the body fluid which encompass several constituents like water, sodium, chlorine, proteins, plasma, amino acids along with mucin in the case of salvia[4]. The aqueous medium in the human body consists of various anions such as chloride, phosphate, and bicarbonate ions cations like Na^+,K^+, Ca^{2+},Mg^{2+},etc.[5-6]. Microorganisms present in the human body can also influence the corrosion behavior of implant materials.

Change In pH Value Affects Corrosion

Change in the pH values also influence the corrosion. Though, the pH value of human body is normally maintained at 7.0, this value changes from 3 to 9 due to several causes such as accidents, imbalance in the biological system due to diseases, infections and other factors and after surgery the pH value near the implant varies typically from 5.3 to 5.6.[2].

Acceptable Corrosion Rate

Acceptable corrosion rate for metallic implant is expected to be 2.5×10^{-4} mm/yr, or 0.01mils/yr [7].

There are mainly two characteristics which determine the implant corrosion.

Thermodynamic driving force

This causes corrosion due to oxidation reduction reaction. Oxidation and reduction are also termed as electron production and electron consumption respectively. The metallic components of the alloys are oxidized to their ionic forms and the dissolved oxygen is reduced to hydroxyl ions. These electrochemical reactions occur on the surface of the surgically implanted biomaterial [1]. Thermodynamic driving forces that cause corrosion correspond to the energy required or released during a reaction [8].

Kinetic Barriers to Corrosion

These are the factors that physically impede or prevent corrosion reactions from taking place [9]. The metals and alloys used as surgical implants achieve passivity by the presence of a protective surface passive film. This film inhibits corrosion and keeps current flow and release of corrosion products at very low level i.e all the implantable materials undergo corrosion at some fine rate due to complex corrosive environment of the body while in use [1]. Only those metals which have the capacity to form protective oxide layer against corrosion can be used in orthopedic implants [8].

CORROSION CHEMISTRY

Electrochemical series; A series in which the metals are listed in the order of their chemical reactivity, the most active at the top and the less reactive or more "noble" metals at the bottom [8]. Gold and platinum are examples of metals that have little or no driving force for oxidation in aqueous solutions, hence they tend to remain in metallic form indefinitely in the human body. However, metals that are commonly used in orthopedics have negative potentials, indicating that from a chemical driving force perspective, they are much more likely to corrode.

Table 1 shows Titanium has a very large negative potential indicating a large chemical driving force for corrosion (oxidation). If some other process such as passivation does not intervene, titanium metal will react violently with surrounding chemical species (typically, oxygen, water, or other oxidizing species) and will revert to its ionic form [8].

These values are based on the standard hydrogen electrode scale. The more noble metals (at the top of the list) are less reactive, while the more active metals (towards the bottom) are more reactive and have a higher driving force for oxidation(corrosion) Note that titanium and chromium (particularly the trivalent form) are both very reactive and have high driving force for oxidation.

Regeneration Time for Surface Oxide Film Contributes in Corrosion of Bioimplant

Time taken for the reformation of surface oxide film after disruption is termed as regeneration time. Corrosion rate following the disruption and the quantity of released metal ions depends upon regeneration time [2].

Regeneration time taken to form surface oxide films for different alloys is illustrated in fig 1.

For these observations it is found that the regeneration time is longer in stainless steel and shorter in Ti-6Al-4V, an alloy which is well known and widely used for orthopedic application, indicating a fact that larger number of metal ions being released from stainless steel compared to Ti-6Al-4V.

Effects of Corrosion on Human Body

When a material starts to corrode, the dissolution of metal will lead to erosion which finally lead to fracture of the implant. Once the material fractures it will accelerates the corrosion rate due to increase in amount of exposed area and loss of protective oxide layer. If the metal fragments are not surgically extracted, further dissolution and fragmentation can occur, which may result in inflammation of the surrounding tissues. Table 2 illustrates the effects of corrosion in human body.

Standard for Testing Corrosion Resistance

There are ASTM standards for testing different corrosion resistance in the material. The most common is given in the table 3.

Invivo and *Invitro* Studies of Corrosion for Bio Implants

Biomedical implants are tested in two different ways which are in the *invivo* tests and the *invitro* tests.

In vitro studies, tests are conducted in laboratory simulating actual body conditions. Though, it gives an idea of how a material may behave under certain circumstances but it cannot be considered as the ultimate test to recommend it as an implant.

On the other hand *in vivo*, tests are conducted using animal's models to observe the actual performance of an implant and these tests have to be approved by FDA (food and drug administration, USA). The *invitro* studies for orthopedic implants are conducted in Hank's Solution and Ringer's Solution.

Various Types of Corrosion in Bioimplant

1. Uniform Corrosion

This refers to the inevitable corrosion to which all metal immersed in electrolytic solutions are condemned [9]

2. Pitting Corrosion

Pitting is a severe form of localized corrosion attack that results in extensive damage and release of significant amount of metal ions. Pitting refers to the formation of small cavities/hole at the surface of material, which is protected otherwise by the presence of an adherent, tenacious and self-healing thin passive film [1] The importance of the pitting significantly depends on the nature of the surface layer or the film that has formed on the surface due to the interaction of the material with the environment. This forces a state of "passivity" which safeguards the material from general corrosion by slowing down the dissolution process at the surface [1].

3. Galvanic Corrosion

Galvanic or two metal corrosion takes place when two different metals are in physical contact in an ionic conducting fluid medium such a serum or interstitial fluid [12]. In surgical implants, galvanic corrosion can occur if bone plate and bone screws are made of dissimilar metals or alloys. Corrosion is likely to occur between the plate and bottom side of the screw holes.

4. Crevice Corrosion

Crevice corrosion is a form of corrosion related to structural details. It occurs when a metal surface is partially shielded from the environment. It is usually encountered beneath screw head that holds the plate or in similar locations such as the intersection of the components of two pieces, hip nails etc[1].

5. Fretting Corrosion

Fretting corrosion occurs when two opposing surfaces such as bone plates and screw heads of the prosthetic devices rub each other continuously in an oscillating fashion in the body environment [1].

It is the result of small relative movements between the contacting surfaces in a corrosive medium.

Table 1. Standard Electrochemical Series for Selected Metals [10]

Noble	Reaction			Potential (Volts)
	$Au3^{+} + 3e^{-}$	⇔	Au	1.42
	$Pt2^{+} + 2e^{-}$	⇔	Pt	1.20
	$Ag^{+} + e^{-}$	⇔	Ag	0.80
	$O_2 + 2H_20 + 4e^{-}$	⇔	OH^{-}	0.40
	$Ti(OH)^{3+} + H^{+} + e-$	⇔	$Ti^{3+}+H_20$	0.06
	$H^{+}+ e-$	⇔	$1/2\ H_2$	0.00
	$Fe3^{+} + 3e^{-}$	⇔	Fe	-0.04
	$Co2^{+} + 2e^{-}$	⇔	Co	-0.28
	$Fe2^{+} + 2e^{-}$	⇔	Fe	-0.41
	$Cr2^{+} + 2e-$	⇔	Cr	-0.56
	$Cr3^{+} + 3e-$	⇔	Cr	-0.74
	$2H_20 + 2e-$	⇔	$20H^{-}$	-0.83
	$Ti0_2 + 4H^{+} + 4e-$	⇔	$Ti+2H_20$	-0.86
	$Ti2^{+} + 2e-$	⇔	Ti	-1.60
Active	$Mg^{+} + e-$		Mg	-2.37
	$Na^{+} + e-$	⇔	Na	-2.71

6. Fatigue Corrosion

Corrosion fatigue is fracture failure of metal that occurs because of the combined interaction of electrochemical reactions and cyclic loading [1]. This corrosive attack will be influenced by solution type, solution pH, oxygen content and temperature. The presence of corrosion pit or pits could induce the fatigue to develop [14].

7. Leaching Corrosion

This form of corrosion results from chemical differences not within boundaries but within the grains themselves [9].The corrosion failure not only impairs the performance of the permanent implants but also the behavior of the temporary implants made of surgical grade type 316 L Stainless steel [13].

Table 2.Effects of Corrosion in Human Body due to Various Biomaterials [12]

Biomaterial Metals	Effect of Corrosion
Nickel	Affects skin - such as dermatitis
Cobalt	Anemia B inhibiting iron from being absorbed into the blood stream
Chromium	Ulcers and Central nervous system disturbances
Aluminum	Epileptic effects and Alzheimer's disease
Vanadium	Toxic in the elementary state

Table 3. Standards for Testing Corrosion Resistance of Biomaterials [13]

ASTM Standards	Specifications
ASTM G 61-86,and ASTM G 5-94	Corrosion performance of metallic biomaterials
ASTM G71-81	Galvanic corrosion in electrolytes
ASTM F746-87	Pitting or crevice corrosion of metallic surgical implant materials
ASTM F2129-01	Cyclic potentiodynamic polarization measurements

Table 4. Types of Corrosion in the Convential Materials Used for Biomaterial Implants [14]

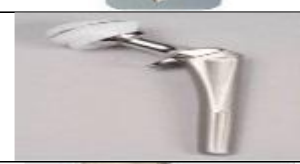
S.No	Type of corrosion	Material	Implant location	Shape of the implant
1	Pitting	304 SS, Cobalt based alloy	Orthopedic/ Dental alloy	
2	Crevice	316 L stainless steel	Bone plates and screws	
3	Crevice	316 L stainless steel	Bone plates and screws	
4	Fretting	Ti6Al4V, CoCrSS	Ball Joints	
5	Galvanic	304SS/316SS, CoCr+Ti6Al4V, 316SS/Ti6Al4V Or CoCrMo	Oral Implants Screws and nuts	
6	Selective Leaching	Mercury from gold	Oral implants	

Fig. 1. Regeneration Time of Surface Oxide Films for Various Alloys [11]

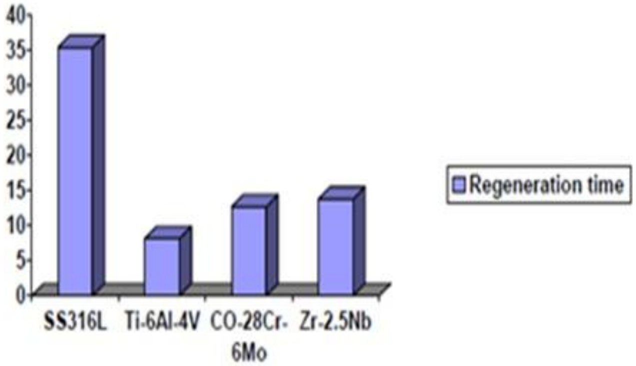
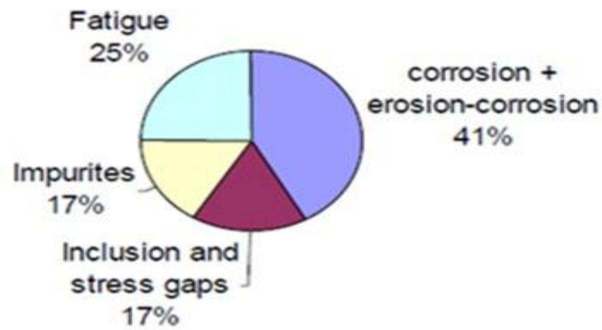


Fig. 2. Failure Analysis of Implant TI6AL4V and 316 L Steel [15]



CONCLUTION

Corrosion is one of the major processes that cause problems when metals and alloys are used as implants in the human body. It is to take place via electrochemical reactions. It is important to realize that corrosion of biomaterials is not just an exercise in Physics and chemistry. It is pertinent clinical issue confronting all orthopedic surgeons, irrespective of the location or the level of sophistication of their practice. It is also important to stress that the adverse effects of corrosion described in this paper do not always occur in patients with implants because the biological response varies among individuals.

REFERENCES

1. Kamachi Mudali U, Sridhar TM and Baldev Raj. (2003). Corrosion of bio implants. *Sadhana*, *2*8, Parts 3 & 4, pp. 601–637.
2. Geetha Manivasagam. (2010). Biomedical implants, Corrosion and its prevention- A review. *Recent patents on corrosion science*, 2, 40-45.
3. Sinha OP. (2012). Potentiodynamic polarization study of Type 316L and 316LVM stainless steels for surgical implants in simulated body fluids. *Journal of chemical and Pharmaceutical research*, 4(1), 203-208.
4. Lawrence SK, Gertrude M. Shults. (1925). Studies on the relationship of the chemical constituents of blood and cerebrospinal fluid. *J Exp Med*, 42(4), 565-91.
5. Scales JT, Winter GD, Shirley HT. (1959). Corrosion of orthopedic implants, screws, plates, and femoral nail-plates. *J Bone Joint Surg*, 41B, 810-20.
6. Williams DF. (1987). Review-Tissue-biomaterial interactions. *J Mater Sci*, 22, 3421-45.
7. Mohanty M, Baby S, Menon KV. (2003). Spinal fixation device: a 6-year postimplantation study. *J Biomater Appl*, 18, 109-21.
8. Black J. (1988). Corrosion and degradation in Orthopaedic biomaterials in research and practice, New York, Churchill, Livingstone, 235-266
9. Akasakal B, Yildirim OS, Gul H. (2004). Metallurgical failure analysis of various implant materials used in orthopedic applications. *J Fail Anal prevent*, 4(3), 17.
10. Jones DA. (1992). Principles and prevention of corrosion. USA: Macmillan Publishing Company, 74-115.
11. Sivakumar M, Kamachi Mudali U, Rajeswari S. (1994). Investigation of failures in stainless steel orthopaedic implant devices: Fatigue failure due to improper fixation of a compression bone plate. *Mater. Sci. Lett*, 13, 142–145
12. Aksakal B, Yildirim ÖS, Gul H. (2004). Failure analysis of implants Ti6Al4V and 316L steel. *J Fail Anal Prevent*, 4(3), 17.
13. Frederick H. Silver, Charles Doillon. (1998). Biocompatibility: polymers: interactions of biological and implantable materials. New York: John Wiley & Sons, 1, 254-580.
14. Blackwood DJ. (2003). Biomaterials: past successes and future problems. *Corrosion Rev*, 21(2-3), 97-124.