Tribocorrosion Aspects of Ti-based Biomedical Implants: Current Concerns and New Directions

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Overview

- Introduction
- Ti based medical implants
- Concerns/early failures
- Tribocorrosion
- Methods to mitigate tribocorrosion
- Summary
CDC (Centre for Disease Control) has estimated that number of people suffering with arthritis will go up to 78 million by the year 2040

Due to excellent mechanical properties, superior corrosion resistance and better biocompatibility exhibited by Ti; Ti is widely used in hip and other joint replacement surgeries (such as shoulder, elbow, or knee) or spinal fixation devices and in dentistry applications like implants, crowns, bridges and other prosthesis.
Titanium is a common material.
Implant application: Orthopedics

- THR surgery is one of the most successful procedures with more than 332K/year
- Accounts approximately 10% Revision surgeries/year

Replacement Burden

<table>
<thead>
<tr>
<th>Year</th>
<th>Hip</th>
<th>Knee</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>10.1%</td>
<td>7.4%</td>
</tr>
<tr>
<td>2013</td>
<td>9.9%</td>
<td>7.2%</td>
</tr>
<tr>
<td>2014</td>
<td>10.1%</td>
<td>9.1%</td>
</tr>
<tr>
<td>2015</td>
<td>10.4%</td>
<td>9.4%</td>
</tr>
</tbody>
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AJRR, 2017
Concerns: Early failure

- Upon implantation, electrochemical interactions are induced by corrosion between the implant material. As a result, complications like pitting, fretting, galvanic corrosion, and stress corrosion occur.

- Implant failure has been also associated with several other causes, such as infections in the implanted area, mechanical loosening, bone resorption, osteolysis and increase in time taken for osseointegration to occur apart from the fibrous tissue formation.
Latest data from AJRR

Most frequently reported Diagnosis Codes for Hip Revisions (<3 months to Revision)
Fourth AJRR Annual Report on Hip and Knee Arthroplasty Data, 2017

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Factors affecting implant failure

- **Metallic ions** are the most common corrosion products and accumulate in the body over the course of time.

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Wear and corrosion: Bio-tribocorrosion

Applications: Orthopedics and Dentistry

Bio-tribocorrosion

A typical definition:

**Tribocorrosion** is an irreversible transformation of material in tribological contact caused by simultaneous **physico-chemical and mechanical** surface interactions.


Tribocorrosion net work led by Prof. Stack, University of Strathclyde
Hip implant: interfaces and biology

Three interfaces

1. Head-cup (sliding-corrosion)

2. Modular junction (Head-neck): Fretting-corrosion

3. Stem-bone Fretting-corrosion

Pelvis
Acetabular cup
Femoral head
Femoral neck
Femur

Micro-movements

Load applied

Femoral stem
Marrow cavity

Wear debris

Fibroblast
Macrophage
Osteoblast
Monocyte

Courtesy to Dr. M. Runa
Toxicity Concerns due to wear debris

Bijukumar et al, Nanotoxicology, 2018

Courtesy to Dr. Bijukumar
Dental implant and interfaces

**Mechanical**
- Masticatory loads
- Micromovements
- Fretting corrosion

**Chemical**
- Saliva
- Fluoride
- Temperature
- pH

**Microbiological**
- Bacterial biofilm

Vieira et al. 2006

Mabilleau et al. 2006
Barao et al., 2011; 2012; 2013

Souza et al. 2010

Inflammatory mediators
Bone resorption
Implant failure

Azzi et al. 2007; Jones 2001
Tribocorrosion: Basic methodology

- **Reference electrode (RE)**
- **Auxiliary electrode (AE)**
- **Working electrode (WE)**

**Tribological system**
- **Sample**
- **Potentiostat**

**Tribocorrosion system** - Contact zone
**Tribology:** Friction coefficients
**Corrosion:** Current or potential changes

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Tribocorrosion: Hip simulator
Key feature of tribocorrosion

Interplay of wear (tribology) and corrosion

Effect of passive film
Effect of dissolved oxygen level
Effect of biofilm or cell adhesion
Effect of protein layer
Effect of 3rd bodies and released metal ions
Integration with bone cells
Hip modular junctions: Fretting-corrosion

- **Objective**
  - Study the electrochemical and mechanical behaviour of commonly used metal alloys (Ti6Al4V and CoCrMo) under simulated static and fretting-corrosion conditions.

Variation in load/contact pressure
- Protein content
- pH variations
- Surface topography

System response from modular junction

CoCrMo

Load

Load

CoCrMo

CoCrMo

Ti

Variation in load/contact pressure

CoCrMo

Load

Protein content

Load

pH variations

Surface topography

Load

CoCrMo

CoCrMo

Ti

CoCrMo

Load

18

 Courtesy to Dr. Royhman
Fretting-corrosion: Experimental set-up

Novelty

Simulated contact geometries and fretting motion

*In situ* information on electrochemical changes vs. friction energy

Vertical displacement amplitudes of 25, 50, 100, 150, and 200 µm.

Artificial joint fluid at pH 3.0 and 7.6
Results: Fretting-corrosion

Friction Energy

Metal ion release map

ICP-MS

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Tribocorrosion: UNCD coatings

Ultra-nanocrystalline Diamond Coatings (UNCD): Dr. Orlando et al.

- High friction
- Low friction
- Sliding starts
- Sliding End
- Sudden Change potential
- Coating life

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Coatings for Ti based implants

Micro-arc Oxidation (MAO) Plasma Electrolytic Oxidation (PEO)

- Electrochemical process of oxidation to create porous ceramic-like bioactive coating

- Calcium
- Phosphorous
- Silicon
- Silver

- Biocompatibility
- Mineralization potential
- Antibacterial function

Park et al. 2010
Della Valle et al. 2012
Uhmet al. 2014

Electrochemical coating process:
- Ca<sup>2+</sup> P<sup>3-</sup> Si<sup>+</sup> Ag

Osteogenic cells

Gittens et al., 2014
Enhanced tribocorrosion resistance

Coating lifetime (≈5 min)
Coating lifetime (≈7 min)

Sliding starts

E\text{Vs Vs SCE}

Time (s)

Untreated
Al Oxide
1-CaP5
1-CaP10
1-CaPAg5
1-CaPAg10
2-CaP5
2-CaP10
2-CaPSi5
2-CaPSi10

Courtesy to Dr. Izabella
Bionfunctionization of Ti

PhD Student: Luciana Daniele Trino

Dr. Paulo Noronha
Lisboa Filho,: Expert in Nanopartcle

Dr. Anne George:
Expert in Protein adhesion and regenerative medicine
Ti-Nanotube

0.35NT_Ca/P

0.70NT_Ca/P
Ti-Nanotube: Corrosion resistance

Current = 2.88E-04 ± 3.59E-05 µA

0.35NT_Ca/P

Significantly lower corrosion rate!!!
Co-authors, Contributors and Collaborators

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- Prof. LUIS ROCHA, Prof. ANA (Brazil)
- Dr. Pourzal, Dr. Lundberg, Dr. Wimmer (RUSH)
Summary

- Medical implants-Titanium is still dominating
- Concerns-on early failure and toxicity
- Tribocorrosion: wear-corrosion synergism
- Ti-Passivation behaviour may induce more tribocorrosion
- Need to consider new surface coatings/modification methods to minimize tribocorrosion
- Further research is required
New journal on Bio-Tribocorrosion

Papers are invited

The Journal of Bio- and Tribo-Corrosion publishes papers in all aspects of tribo-corrosion, ranging from biological environments to green energy technologies to bio-degradable metals and polymer composites.
**Introduction:** We understand the need of multi-disciplinary research team to generate innovative solution to the critical clinical issues related to biocompatibility and durability of implants and formulating better clinical treatment/management.

This Institute main focus on the research and teaching related to development and characterization of the biomaterials for the clinical applications. The team consists of clinicians, material scientists and mechanical engineers from College Of Dentistry-Restorative Dentistry and College of Engineering-Bioengineering at the University of Illinois at Chicago (UIC), Department of Mechanical Engineering at Michigan Technological University (MEEM-MTU), and Department of Orthopedics at Rush University Medical Center (RUMC).

**Mission statement:** Our mission is to contribute to the advance of scientific knowledge in biomaterials (development, surface modifications and characterization) for the versatile clinical application for generating and maintaining implants with required durability and multifunctional performance.

**Vision statement:** IBTN aims to be a leading research institute in the area of biomaterial and bioengineering for multifunctional, durable and safer implants in the health care sector, particularly in dentistry and orthopedics.
RMDR lab at UIC-Rockford

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Thank you
Back up slides
Craniomaxillofacial and oral implants

Custom made TMJ implant replacement

Natural tooth vs implant attachment to bone

http://tmjconcepts.com/implant-photo-gallery/mandibular-fossa-reconstruction/
The survival rates for the dental implants range from 90% to 96.5%.

Titanium can be casted into single-and multiple-unit crown and bridge frameworks, implant-supported structures and partial or full denture bases.

The metal oxidizes almost instantaneously in air to form a tenacious and stable oxide layer becoming bioinert which is why Ti is mostly preferred for dental applications.
Implant application: Orthopedics

Total Hip Replacement

Bone Plates

Additive Manufacturing

Source: Autodesk Within Medical Quara.com

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