USE OF DISSIMILAR METALS IN ORTHOPAEDIC IMPLANTS

RAVI SHETTY*

Investigation performed at the Research Laboratories of Zimmer Inc., Warsaw, Indiana

Summary: Dissimilar metals are used in the construction of orthopaedic implants to achieve best results from devices constructed of these metals. In this paper, galvanic corrosion, consequences of galvanic corrosion and clinical use of acceptable metal combinations are described.

Introduction

The use of orthopaedic implants comprised of dissimilar metal components requires careful consideration of dissimilar metal interactions. Implantation of an inappropriate combination of metals or alloys can result in galvanic corrosion. There are both acceptable and unacceptable metal combinations. Device manufacturers have found acceptable combinations of metal components such as Ti-6Al-4V hip stems fitted with Co-Cr-Mo modular heads. However, the surgeon may be confronted with dimensionally compatible device components which, if assembled, will produce significant amounts of galvanic corrosion *in vivo*. For instance, 316L stainless steel bone screws will fit in the SCP slots of Ti-6Al-4V forearm bone plates; however, implantation of such an assembly will result in galvanic corrosion of the 316L stainless steel bone screws. An understanding of the galvanic corrosion process is important to assure proper utilization of metal orthopaedic implants.

Galvanic Corrosion

Galvanic corrosion is a form of metallic deterioration that can occur when two dissimilar metals are placed in physical contact while exposed to electrically conductive fluids. Two dissimilar metal implant components in body fluid can represent a galvanic corrosion situation. Galvanic corrosion occurs because different metals and alloys inherently possess different electrochemical characteristics. When a so-called active metal is in contact with a so-called noble metal, electrons will flow spontaneously from the active metal to the noble metal. Each of the two dissimilar metals and the conductive fluid comprise one half of a battery similar to those used to generate electricity. The loss of electrons experienced by the active metal is termed oxidation and the products of the oxidation process can be seen as corrosion (pitting, rust, etc.).

*Ravi Shetty is Director, Global Metals Research, Zimmer, Inc., where he is responsible for metals research and process development. He holds B.S., M.S., and Ph.D. degrees in metallurgical engineering from the Indian Institute of Science, Bangalore, India. Dr. Shetty has twenty-three years of experience in metals research, of which sixteen years have been in the area of orthopaedics. He holds nine United States patents and has published over 25 papers in national and international journals.

Consequences of Galvanic Corrosion

Galvanic corrosion of an implantable device can create a variety of undesirable effects. The metal ions released from corrosion reactions can cause inflammatory responses, metal sensitivity reactions, and/or long-term detrimental systemic effects. In addition, the corrosion process can damage the surface of the implant and create "stress raisers" which reduce the mechanical strength of the implant.

TABLE 1

Acceptable and Unacceptable Dissimilar Metal and Alloy Combinations

Dissimilar Metal Combinations	Galvanic	References
Ti-6Al-4V/Cast Co-Cr-Mo	Acceptable	1,2,3
Wrought Co-Cr-W-Ni/Cast Co-Cr-Mo	Acceptable	1,4
Wrought Co-Cr-W-Ni/Forged Co-Cr-Mo	Acceptable	
CP Titanium/Forged Co-Cr-Mo	Acceptable	5
CP Titanium/Cast Co-Cr-Mo	Acceptable	
CP Titanium/Ti-6Al-4V	Acceptable	
22-13-5 Stainless/316L Stainless	Acceptable	6
316L Stainless/Cast Co-Cr-Mo	Do Not Use	1,2,5
316L Stainless/ Ti-6Al-4V	Do Not Use	1,2
316L Stainless/CP Titanium	Do Not Use	
316L Stainless/Forged Co-Cr-Mo	Do Not Use	
316 Stainless/Wrought Co-Cr-W-Ni	Do Not Use	
22-13-5 Stainless/Cast Co-Cr-Mo	Do Not Use	
22-13-5 Stainless/Ti-6Al-4V	Do Not Use	
22-13-5 Stainless/CP Titanium	Do Not Use	
22-13-5 Stainless/Forged Co-Cr-Mo	Do Not Use	
22-13-5 Stainless/Wrought Co-Cr-W-Ni	Do Not Use	

Clinical Use of Dissimilar Metal Combinations

In years past, all dissimilar metal combinations in orthopaedic devices were considered unacceptable under any circumstances. More recently, however, a few particular dissimilar metal combinations have been shown to produce only a negligible rate of corrosion in a physiological environment. The lower rates of corrosion in these particular combinations are due to the closely matched electrical potentials of the dissimilar metals or alloys. Careful design of orthopaedic devices with these acceptable metal combinations can improve device performance by allowing maximal utilization of the favorable attributes (e.g. strength, biocompatibility, and wear resistance) of each alloy.[7]

Only those dissimilar metal combinations which produce a negligible corrosion rate are considered acceptable for use in orthopaedic implants. Table 1 lists acceptable and unacceptable dissimilar metal combinations. To assist in the interpretation of Table 1, a list of metals commonly used for orthopaedic implantable devices is given in Table 2.

TABLE 2

Metals Used for Orthopaedic Implantable Devices

Alloy Name	Major Constituent	Major Alloying Elements	ASTM Designation	Other Designations	Typical Applications
ELI Ti-6Al-4V	Titanium (Extra Low Interstitial Grade)	Aluminum (5.5%-6.5%) Vanadium (3.5%-4.5%)	F136		Hip Prostheses, Knee Prostheses, Bone Plates, Bone Screws
Commercially Pure Titanium (CP Titanium)	Titanium	Oxygen (exact amount depends on the application)	F67		Acetabular Cups Suture Wire Fiber Metal
High-Strength Forged Co-Cr-Mo	Cobalt	Chromium (26%-30%) Molybdenum (5%-7%)	F799	Wrought Haynes Stellite (HS) 21	Hip Prostheses
Cast Co-Cr-Mo	Cobalt	Chromium (27%-30%) Molybdenum (5%-7%)	F75	Cast Haynes Stellite (HS) 21, UNS R30021	Endoprostheses Knee Prostheses, Modular Heads for Hip Prostheses
Wrought Co-Cr-W-Ni (L-605)	Cobalt	Chromium (19%-21%) Tungsten (14%-16%) Nickel (9%-11%)	F90	Haynes Stellite (HS) 25, UNS R30605	Suture Wire
316L Stainless Steel	Iron	Chromium (17%-19%) Nickel (12%-14%) Molybdenum (2%-3%)	F138 Grade 2	SAE 30316L UNS S31603	Fracture Fixation Devices (Hip Screws, Bone Plates, Bone Screws, Intramedullary Nails), Suture Wire
22-13-5 Stainless Steel	Iron	Chromium (20.5%-23.5%) Nickel (11.5%-13.5%) Manganese (4%-6%) Molybdenum (2%-3%) Nitrogen (0.20%-0.40%) Niobium (0.10%-0.30%)	F1314	UNS S20910	Fracture Fixation Devices (Compression Hip Screws)

Cautionary Notes

The information in Table 1 describes only those applications in which contacting dissimilar metals do not move relative to each other in a repetitive manner. Very small repetitive relative motion (called fretting) can lead to breakdown of the protective oxide films on orthopaedic alloys and can thus significantly alter corrosion characteristics at the site of the relative motions.

Galvanic (dissimilar metal) corrosion should not be confused with crevice corrosion. Crevice corrosion can occur when a crevice is established between two contacting pieces of metal, even if the two pieces are metallurgically identical. Such a configuration is created, for example, at the junction between a bone screw and a bone plate. (The screw/bone plate interface may also be a site of fretting corrosion.)

The information in Table 1 applies only to devices which have been manufactured from uniform "high quality" raw materials with a high degree of microcleanliness. Microstructural nonuniformities (such as inclusions or nonuniform grain size) have been shown to alter the corrosion resistance of orthopaedic metals.[8]

References

1. **Rostocker W, Pretzel CW, Galante JO.** Couple corrosion among alloys for skeletal prostheses. *J Biomed Mater Res.* 1974;8:407-419.
2. **Griffin CD, Buchanan RA, Lemons JE.** *In vitro* electrochemical corrosion study of coupled surgical implant materials. *J Biomed Mater Res.* 1983;17:489 500.
3. **Lucas LC, Buchanan RA, Lemons JE.** Investigations on the galvanic corrosion of multialloy total hip prostheses. *J Biomed Mater Res.* 1981;15:731-747.
4. **Rostocker W, Galante JO, Lereim P.** Evaluation of couple/crevice corrosion by prosthetic alloys under *in vivo* conditions. *J Biomed Mater Res.* 1978;12:823-829.
5. **Kummer FJ, Rose RM.** Corrosion of titanium/cobalt-chromium alloy couples. *J Bone Joint Surg Am.* 1983;65A(8):1125-1126.
6. **Shetty HR, Jacobs CH.** Galvanic corrosion properties of 22-13-5/316L stainless steel couple in physiologic solution. *Trans Soc Biomat.* 1987;10:231.
7. **Mears DC.** The use of dissimilar metals in surgery. *J Biomed Mater Res.* 1975;6:133-148.
8. **Cook SD, Renz EA, Barrick RL, et al.** Clinical and metallurgical analysis of retrieved internal fixation devices. *Clin Orthop.* 1985;194:236-247.