Degradation of Implant Materials

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Editor

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Preface

The degradation of biomaterials is one of the major considerations in their design, processing, and use. It might be undesirable (e.g., corrosion of metallic dental implants, wear of polyethylene in artificial hip joints, or calcification of stents), but in other cases it may be desirable (e.g., absorbable sutures, biodegradable polymers for drug delivery, or tissue engineering). In both cases, the kinetics of the degradation is of paramount importance. The undesirable degradation might lower the structural integrity of the implant or release metal ions and debris that elicit an adverse biological reaction (possibly causing synovitis, periprosthetic bone loss, cytotoxicity, allergy, or even cancer).

This book summarizes the current understanding of the mechanical, chemical, and biological processes that are responsible for the degradation of a variety of implant materials. The 18 chapters were written by internationally renowned experts and address both fundamental and practical aspects. Different failure mechanisms such as corrosion, fatigue, and wear are reviewed, together with experimental techniques for monitoring them, either i*n vitro* or *in vivo*. Procedures for implant retrieval and analysis are presented. A variety of biomaterials (stainless steels, titanium and its alloys, magnesium alloys, polyethylene, polycarbonate-urethane, biodegradable polymers, calcium phosphates, etc.) and medical devices (orthopaedic and dental implants, stents, heart valves, etc.) are analyzed in detail.

In Chap. 1, *J.L. Gilbert* and *S. Mali* present the complex interactions that occur in the human body during corrosion of metallic implants. The concepts associated with oxide films and their interaction with the biological, mechanical, and electrochemical environments are discussed, as is mechanically assisted corrosion. Specific examples of biotribocorrosion are discussed. In Chap. 2, *S. Virtanen* summarizes the state-of-the-art knowledge on the degradation modes of titanium and biomedically relevant Ti-based alloys. Issues such as passivity, the effect of alloying elements, and tribocorrosion are discussed comprehensively. A short discussion on some relevant implant design-related aspects of degradation is also provided.

In Chap. 3, *T. Hanawa* reviews different aspects of the degradation of dental implants. Issues such as wear and fracture, the biological environment, corrosion, metal ion release, biofilm formation, and contamination are discussed briefly. Materials such as titanium and its alloys, calcium phosphates, and zirconia are analyzed. In Chap. 4, *T. Eliades*, *S. Zinelis* and *W.A. Brantley* extend the discussion on dental implants—their aging, corrosion, and failure.

Chapter 5, by *F. Witte* and *A. Eliezer*, starts a series of chapters which describe positive effects and applications of controlled degradation. This chapter covers different aspects of biodegradable implants, with focus on magnesium- and iron-based alloys, and absorbable stents. In Chap. 6, *A.R. Boccaccini et al.* discuss bioactive and biodegradable scaffolds for bone tissue engineering, which are made of a synthetic biodegradable polymer matrix, such as poly(D,L-lactide) (PDLLA), and an inorganic reinforcement such as Bioglass®. In Chap. 7, *J.A. Jansen et al.* discuss different factors that influence the biodegradation of calcium phosphate cements. These cements are good candidates as bone grafts in dental, orthopaedic, and reconstructive surgery. In Chap. 8, *N. Lotan*, *R. Azhari*, and *T. Gold* present the design and performance evaluation of an implantable, degradable, drug delivery device, the function of which is controlled by the concentration and activity of a given enzyme present at the site of implantation. In Chap. 9, *J. Chevalier et al.* comprehensively review the degradation mechanisms of ceramic implants, both bioinert and bioactive, and the interactions between them and their environment. Crack propagation mechanisms are discussed, along with a variety of materials such as hydroxyapatite and other calcium phosphates, calcium sulfate, bioactive glasses, and composites of them.

Chapter 10, by *N. Eliaz* and *K. Hakshur*, starts a series of chapters which focus on the outcomes of wear and fatigue of biomaterials and implants. This chapter first gives brief introduction to the three elements of tribology—friction, lubrication, and wear. Subsequently, the principles and use of Ferrography and Bio-Ferrography in isolating wear debris and monitoring either the degradation of bone and cartilage during osteoarthritis or the degradation of hip and knee artificial joints are reviewed comprehensively. The concept of soft bearing materials such as polycarbonate-urethane (PCU) is presented. In Chap. 11, *S.H. Teoh*, *Y.L. Teo*, and *S.K. Chong* discuss fatigue failures of medical devices. First, basic fundamentals and terminologies in fatigue mechanics are presented. Subsequently, case studies of failures of hip and knee prostheses as well as of dental restoratives are discussed. In Chap. 12, *N.J. Hallab* reviews the topic of hypersensitivity to implant debris. Metal sensitivity, related tests, and case studies are presented.

Chapter 13, by *C.R. Arciola*, *D. Campoccia*, and *L. Montanaro*, discusses implant infections, historical approach to their prevention, and infection-resistant materials. In Chap. 14, *N. Vyavahare*, *F. Schoen*, and *A. Munnelly* discuss mechanisms and prevention strategies of calcification in the two classes of implants: biologically derived and synthetic. Calcification of bioprosthetic heart valves, collagen and elastin tissue engineering scaffolds, polyurethane, silicone breast implants, hydrogels and ophthalmic implants, and intrauterine devices (IUDs) is reviewed.

Chapter 15, by *L.C. Jones*, *A.K. Tsao*, and *L.D.T. Topoleski*, reviews the significance of retrieved orthopaedic implants and failure analysis to their long-term survival. Issues such as the musculoskeletal system, orthopaedic implants, failure, preclinical and clinical testing, implant retrieval programs, the role of materials selection and implant design, and biological responses to implants are discussed comprehensively. In Chap. 16, *M. Wu* and *P. Briant* summarize the use of finite element analysis (FEA) in design, life prediction, and failure analysis of biomaterials and medical devices. Nitinol wire frame based inferior vena cava filter (IVCF) is given as a case study.

Chapters 17 and 18 discuss the biological responses to and toxicity of polymers and nanomaterials, respectively. First, in Chap. 17, *J.C. Park* and *B.J. Park* review the biological response following implantation of biodegradable polymers and some methods for biological safety evaluation of biodegradable materials recommended by the International Organization for Standardization (ISO) and the US Food and Drug Administration (FDA). Nanomaterial safety and toxicity are of great importance for nanomaterial-based medical implants. Then, in Chap. 18, *T.J. Webster* and *L. Yang* introduce the host responses to implant materials and properties of nanomaterials pertinent to their altered biological responses. Next, the advances and progression of biological responses (especially concerning the toxicity of nanoscale implant materials, either after production or implantation) are summarized.

I hope that this book will become a reference source for undergraduate and graduate students, college and university professors, scientists, engineers, implant manufacturers, venture capitalists, regulatory entities, and research professionals working both in academia and industry. It may be of interest to materials, mechanical, biomedical, and corrosion engineers; biologists and medical doctors; chemists and electrochemists; surface scientists; failure analysts; etc.

I dedicate this book to my wife Billie and our three children—Ofri, Shahaf, and Shalev—for their infinite love and support.

Tel-Aviv, Israel Noam Eliaz

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Biography

Professor Noam Eliaz

Noam Eliaz is an Associate Professor at Tel-Aviv University, Israel, where he serves as the Head of the Biomaterials and Corrosion Laboratory. He also serves as a Chief Editor of the journal *Corrosion Reviews* (jointly with Ron Latanision). He received his B.Sc. and Ph.D. (direct track) in Materials Engineering, both cum laude, from Ben-Gurion University. Next, he became the first ever materials scientist to receive, simultaneously, a Fulbright postdoctoral award and a Rothschild postdoctoral fellowship and worked for 2 years in the H.H. Uhlig Corrosion Laboratory at M.I.T. To-date, he has contributed more than 230 journal and conference publications, including 31 plenary and invited talks, as well as 5 book chapters. In addition to editing this *Degradation of Implant Materials* book, he has edited a double volume entitled “Applications of Electrochemistry and Nanotechnology in Biology and Medicine” for the reputed book series *Modern Aspects of Electrochemistry* (Springer). He has garnered numerous accolades, including the T.P. Hoar Award for the best paper published in *Corrosion Science* during 2001 (on corrosion of Ti–Ag-based alloys processed by three-dimensional printing for biomedical applications) and NACE International's Herbert H. Uhlig Award (2010) and Fellow Award (2012). His main research interests include environment-induced degradation of materials, failure analysis, Bio-Ferrography, biomaterials (with focus on electro-crystallization of hydroxyapatite and other calcium phosphates), and electrochemical processing (namely, electrodeposition, electroless deposition, and electropolishing) of materials.