Materials Science and Engineering C 55 (2015) 227–251

Contents lists available at ScienceDirect

Materials Science and Engineering C

journal homepage: www.elsevier.com/locate/msec

Review

Bio-functional nano-coatings on metallic biomaterials

Anil Mahapatro *

Bioengineering Program & Department of Industrial and Manufacturing Engineering, Wichita State University, Wichita, KS, 67260, United States

ARTICLE INFO

Article history:
Received 10 July 2014
Received in revised form 20 March 2015
Accepted 7 May 2015
Available online 9 May 2015

Keywords:
Nanocoatings
Metallic biomaterials
Surface modification
Self-assembled monolayers (SAMs)

ABSTRACT

Metals and their alloys have been widely used in all aspects of science, engineering and medicine. Metals in biomedical devices are used due to their inertness and structural functions. They are generally preferred over polymers or ceramics and are especially desirable in applications where the implants are subjected to static, dynamic or cyclic loads that require a combination of strength and ductility. In biomedicine, the choice of a specific biomaterial is governed by many factors that include biocompatibility, corrosion resistance, controlled degradability, modulus of elasticity, fatigue strength and many other application specific criterions. Nanotechnology is driving newer demands and requirements for better performance of existing materials and presents an opportunity for surface modification of metals in response to demands on the surface of metals for their biomedical applications. Self-assembled monolayers (SAMs) are nanosized coatings that present a flexible method of carrying out surface modification of biomaterials to tailor its surface properties for specific end applications. These nanocoatings can serve primary functions such as surface coverage, etch protection and anti-corrosion along with a host of other secondary chemical functions such as drug delivery and biocompatibility. We present a brief introduction to surface modification of biomaterials and their alloys followed by a detailed description of organic nanocoatings based on self-assembled monolayers and their biomedical applications including patterning techniques and biological applications of patterned SAMs.

Contents

1. Introduction

Since early ages humans have tried to restore function to the human body stricken with trauma or disease and often metals and other materials have been used for this purpose in the form of an implant or other biomedical devices [1]. Implant materials help people with diseased joints walk without pain on artificial joints and help people with defective hearts to lead normal lives with pacemakers and artificial heart valves [2]. Biomaterials can be broadly classified into three major categories: metals, polymers and ceramics [3]. Among the classes of biomaterials, metals are the most widely used in biomedical devices including implant materials [4]. Metals in biomedical device are exploited due to their inertness and structural functions. Since they do not possess

* Bioengineering Program & Department of Industrial and Manufacturing Engineering, Wichita State University, 1845 Fairmount Street, Wichita, KS 67260, United States.
E-mail address: anil.mahapatro@wichita.edu.
URL: http://www.wichita.edu/anil.

http://dx.doi.org/10.1016/j.msec.2015.05.018
0928-4931/

bio-functionalities like blood compatibility and bioactivity surface modifications may be required [5,6]. For example many implanted biomedical devices suffer from infections that develop post surgically on the device surface, which could cause device failure [7–9]. This problem is critical and escalating and of particular urgency are infections from orthopedic implants, which require that the patient undergo two or more additional surgeries with multi-week gaps in between [10–12]. Nanoscience and nanotechnology have been driving a lot of research in laboratories around the world and this field offers tremendous promise in its ability to modify the surface properties of biomaterials without altering the bulk properties of the biomaterial [13–18]. The advantages of nanoscience and nanotechnology are already visible in the fields of organic electronics, electronics and biomedicine [19–30]. Nanoscience can be termed as the science of objects with the smallest dimensions in the range of a few nanometers to a hundred nanometers [21, 31–45]. Some examples of materials that fall in this size range are colloids, micelles, polymer molecules, buckytubes and buckyballs, quantum dots, phase separated polymers, self-assembled monolayers, phase separated regions in block copolymers, very large molecules or aggregates of large molecules [31,46–50]. On the nanoscale, controlling the surface and interfacial properties becomes critical as almost 90% of all biological reactions and host response happens at the surface of the substrate [51–54]. There is an increase in the surface area of nanostructured materials, since as compared to macroscopic materials, a large percentage of the constituent atoms for the nanostructured materials are at the surface. This kind of scaling behavior leads to structures where nearly every atom in the structure is interfacial [19]. Thus the structures and chemical assemblies of nanostructures and nanoassemblies have a direct impact on the macroscopic properties of the material. Self-assembled monolayers (SAMs) are nanosized coatings that present a flexible method of carrying out surface modification of biomaterials to tailor its surface properties for specific end applications. These nanocoatings can serve primary functions such as surface coverage, etch protection and anti-corrosion along with a host of other secondary chemical functions such as drug delivery and biocompatibility. In this review we have presented a comprehensive literature review on nanocoatings on metallic biomaterials with special emphasis on self-assembled monolayers, their biomedical applications including patterning techniques and biological applications of patterned SAMs.

2. Metallic biomaterials

Metals have been reported to be used in surgical procedures from as early as 1565 when Petronium recommended the use of gold plates for the repair of cleft palates [4]. Since then metallic implants have found various applications and have been used in orthopedics as prostheses or fixation devices [2]. Prostheses serve to replace a portion of the body such as joints, long bones and skull plates. Fixation devices (Fig. 1) [55] are used to stabilize broken bones and other tissues while the bone and tissue heals. Orthopedic surgeries now accounts for the largest use of metals in the body [56]. These include a wide range of devices ranging from simple wires and screws to fracture-fixation plates and total joint prostheses (artificial joints) for hips, knees, shoulders, elbows, etc. In addition to orthopedics, metallic implants are widely used in oral and maxillofacial surgery and cardiovascular surgery [57–59]. In the area of orthopedics metals are popular because of their ability to bear significant loads, withstand fatigue loading and undergo plastic deformation prior to failure [60]. The different metals/alloys used in orthopedic applications are F55 and F138 low carbon stainless steel (SS 316L), F75 and F90 cobalt–chromium alloys, F76 commercially pure titanium and F136 titanium–aluminum–vanadium alloy (Ti–6Al–4V) [1,51,60, 61]. 316L stainless steel has been extensively used in the case of fracture fixation devices. Compared to titanium alloys, stainless steel exhibits superior modulus of elasticity and tensile strength (Table 1) [62]. It also has good ductility and possesses good biocompatibility [63,64]. Cobalt–chromium alloys are highly corrosion resistant and compared to stainless steel they have higher elastic modulus, strength and hardness [1,2,65]. They possess adequate fatigue properties to serve as artificial joints or total joint prostheses [66]. Titanium based alloys are the materials of choice for bone related applications such as dental and

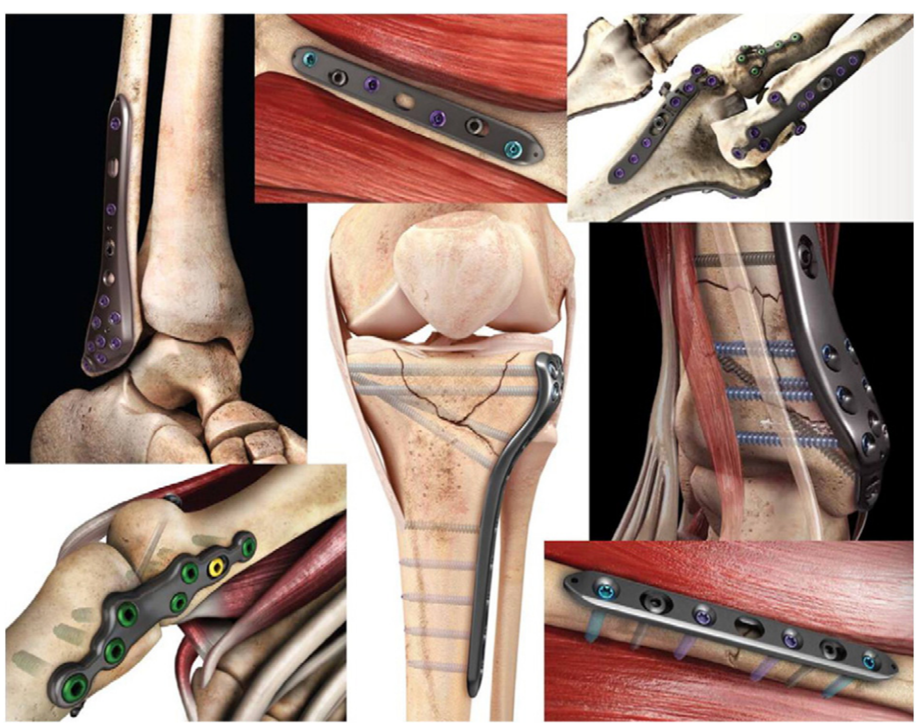

Fig. 1. Representative example of application of metallic biomaterials: bone fixation devices.
Reprinted with permission from Ref. [55], M. S. Scholz, J. P. Blanchfield, L. D. Bloom, B. H. Coburn, M. Elkington, J. D. Fuller, M. E. Gilbert, S. A. Muflahi, M. F. Pernice, S. I. Rae, J. A. Trevarthen, S. C. White, P. M. Weaver, and I. P. Bond, The use of composite materials in modern orthopaedic medicine and prosthetic devices: a review, Comp. Sci. and Tech., 71, 1791–1803, (2011). Copyright @ Elsevier.