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Collagen I-Coated Titanium Surfaces for Bone Implantation

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Biological interactions at the tissue/implant material interface can be modulated by surface-linked cell-signalling biological molecules. Collagen type I, the main extracellular matrix protein of bone tissue, has been widely investigated in biomolecular surface modification of bone-contacting titanium implant devices. Literature reports on the biological effects of collagen-based coatings are, however, often contradictory. From a biomolecular surface-engineering perspective, a possible explanation is that the definition "collagen-coated surface" encompasses widely different molecular and supramolecular structures: adsorbed collagen, covalently linked collagen, crosslinked collagen, fibrillar versus monomeric collagen, and many other variation of this theme. Relevant details are not always described and proper surface characterization is often lacking. This chapter attempts to build up a rational frame of reference to describe surface modification of implant devices by collagen type I from a surface chemistry point of view, as well as to discuss relevant implications for process design.

Abbreviations

AFM	atomic force microscopy
Arg–Gly–Asp	arginine–glycine–aspartic acid
BMTiS	biochemical modification of titanium surfaces
Co	cobalt
DAE	double acid etched
ECM	extracellular matrix
EDC	1-ethyl-3-(3-dimethylaminopropyl)-carbodiimide
NHS	*N*-hydroxysuccinimide
OC	osteocalcin
OP	osteopontin
PBS	phosphate-buffered saline
PDGF	platelet-derived growth factor

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PDL	periodontal ligament
PEG	poly(ethylene glycol)
RGD	arginine–glycine–aspartic acid
RT-PCR	real-time polymerase chain reaction
Ti	titanium
Ti6Al4V	titanium/aluminum/vanadium alloy
ToF-SIMS	time-of-flight static secondary ion mass spectroscopy
UHV	ultra-high vacuum
XPS	X-ray photoelectron spectroscopy

19.1. Introduction

Titanium has gained wide acceptance for load-bearing, bone-contacting devices since the pioneering work of Branenmark. Nowadays, Ti implant devices are used for a variety of applications; most of the techniques in use are evidence-based and predictable. Because interactions at the bone-implant interface are recognized as the key to osteointegration and the literature on titanium surfaces and interfaces is extensive [1–4], numerous approaches focusing on the surface modification of titanium to further improve clinical results and extend the spectrum of biomedical applications have been developed. Despite its significant success as a biomaterial, Ti and its surface are still actively investigated for applications such as dental implantology, where the need exists to address difficult clinical settings, e.g., an intended implant site compromised because of poor bone quality. Examples of poor bone quality include, for instance, low bone density in the case of highly cancellous bone and insufficient quantity of bone (in the case of the width of the alveolar ridge). In the case of artificial vertebral discs, Cunningham recently suggested that the most important and challenging aspect for the success of orthopaedic implants is to achieve osseointegration at the bone-metal interface while preserving the necessary biomechanical properties of motion [5]. In both dental implantology and orthopaedic applications, increased life expectancy of human subjects poses new challenges: novel surface treatment of implant devices are needed to improve bone density locally, to accelerate healing, and to perform with dependability during integration even in old or pathologic bone for long periods of time.

Traditionally, the approach to surface modification of titanium has been based on the control of surface topography [3], on physicochemical [6] and inorganic approaches, and on the use of ceramic coatings [7]. Presently, a significant research effort is aimed at the biochemical modification of titanium surfaces (BMTiS); these strategies were described by Puleo and Nanci [8] as follows: "Biochemical surface modification endeavours to utilize current understanding of the biology and biochemistry of cellular function and differentiation. Much has been learned about the mechanisms by which cells adhere to substrates, and major advances have been made in understanding the role of biomolecules in regulating differentiation and remodelling of cells and tissues, respectively. The goal of biochemical surface modification is to immobilize proteins, enzymes, or peptides on biomaterials for the purpose of inducing specific cell and tissue responses or, in other words, to control the tissue implant interface with molecules delivered directly to the interface.... In contrast to calcium phosphate coatings, biochemical surface modification utilizes critical organic components of bone to affect tissue response."

Among the organic components of bone, collagen is most important and of special interest: the extracellular matrix (ECM) of bone contains approximately 85% type I collagen.