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Impact of plasma chemistry versus titanium surface topography on osteoblast orientation

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ABSTRACT

Topographical and chemical modifications of biomaterial surfaces both influence tissue physiology, but unfortunately little knowledge exists as to their combined effect. There are many indications that rough surfaces positively influence osteoblast behavior. Having determined previously that a positively charged, smooth titanium surface boosts osteoblast adhesion, we wanted to investigate the combined effects of topography and chemistry and elucidate which of these properties is dominant. Polished, machined and corundum-blasted titanium of increasing microroughness was additionally coated with plasma-polymerized allylamine (PPAAm). Collagen I was then immobilized using polyethylene glycol diacid and glutar dialdehyde. On all PPAAm-modified surfaces (i) adhesion of human MG-63 osteoblastic cells increased significantly in combination with roughness, (ii) cells resemble the underlying structure and melt with the surface, and (iii) cells overcome the restrictions of a grooved surface and spread out over a large area as indicated by actin staining. Interestingly, the cellular effects of the plasma-chemical surface modification are predominant over surface topography, especially in the initial phase. Collagen I, although it is the gold standard, does not improve surface adhesion features comparably.

1. Introduction

The metallic implants used in orthopedic surgery or oral implantology can be regarded as bone-replacing and bone-contacting applications, and include joint and tooth replacement, fracture healing and reconstruction of skeletal abnormalities. For these implants, the ultimate goal is to obtain a lifelong secure anchorage in the native surrounding bone. Due to its excellent mechanical properties, biocompatibility as well as corrosion resistance, commercially pure titanium has been widely used as an implant material in various dental and orthopedic applications [1–4]. For the efficacy of these implants, it is essential to establish a mechanically solid interface with complete fusion between the material's surface and the bone tissue without fibrous tissue interface [5].

Although it is well established that titanium is an osteoconductive material, little precise knowledge has been established to ascertain whether titanium chemistry or topography is the more crucial factor in determining the level of osteoconductive capacity: it is a big challenge to change only one factor without changing the other because the surface chemistry and topography of titanium are interrelated [6]. The influence of surface topography has been widely reported and plays an important role in cell behavior [6–8]. Osteoblast-like cells cultured in vitro on rough surfaces show stronger cell adhesion and spreading [7,9] and high production of both differentiation-associated growth factors and extracellular matrix proteins [10–12]. Surface modifications which alter the topography of the titanium surface mainly include mechanical methods, such as machining, grinding, polishing and blasting, and chemical methods, such as etching and anodization [7,8,13–16].

Another approach towards the creation of a biologically active implant surface involves the application of an additional layer onto the titanium surface by means of physicochemical and biochemical deposition techniques [17,18]. One main focus concerning the chemical modification of material surfaces involves coating with proteins. Because collagen is a ligand which facilitates the cell adhesion via integrins, coating with adhesion proteins or peptides (especially RGD) and/or growth factors is of great interest [19,20]. Another strategy utilizes the net negative charge of eukaryotic cells by providing the surface with positive charge carriers, e.g. NH_2 groups [21–24]. Plasma modification of titanium surfaces with allylamine renders the surface more hydrophilic and generates positively charged amine groups [23,24]. Allylamine is widely used as a precursor for providing materials with a net positive surface charge and for allowing further covalent coupling of proteins or peptides via suitable linkers [17,25–27]. However, previous research has merely tested the influence of the plasma-polymerized

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