Treatments for enhancing the biocompatibility of titanium implants. A review

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Titanium surface treatment is a crucial process for achieving sufficient osseointegration of an implant into the bone. If the implant does not heal sufficiently, serious complications may occur, e.g. infection, inflammation, aseptic loosening of the implant, or the stress-shielding effect, as a result of which the implant may need to be reoperated. After a titanium graft has been implanted, several interactions are crucial in order to create a strong bone-implant connection. It is essential that cells adhere to the surface of the implant. Surface roughness has a significant influence on cell adhesion, and also on improving and accelerating osseointegration. Other highly important factors are biocompatibility and resistance to bacterial contamination. Bio-inertness of titanium is ensured by the protective film of titanium oxides that forms spontaneously on its surface. This film prevents the penetration of metal compounds, and it is well-adhesive for calcium and phosphate ions, which are necessary for the formation of the mineralized bone structure. Since the presence of the film alone is not sufficient for the biocompatibility of titanium, a suitable surface finish is required to create a firm bone-implant connection. In this review, we explain and compare the most widely-used methods for modulating the surface roughness of titanium implants in order to enhance cell adhesion on the surface of the implant, e.g. plasma spraying, sandblasting, acid etching, laser treatment, sol-gel etc. The methods are divided into three overlapping groups, according to the type of modification.

Key words: titanium treatment, osseointegration, biocompatibility, surface modification

Received: November 20, 2019; Revised: December 15, 2019; Accepted: December 17, 2019; Available online: January 6, 2020

https://doi.org/10.5507/bp.2019.062
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INTRODUCTION

Bone is the second most commonly transplanted tissue\textsuperscript{1,2}. For present-day treatment of degenerative diseases, such as arthritis and traumatic bone damage, the replacement of bone tissue by an implant is an option when conservative treatment has already failed. Bone tissue is characterized by excellent regenerative and remodelling capabilities. There are several methods for treating bone diseases and injuries. In the case of small-scale tissue damage, the bone is self-regenerating. For larger-scale injuries, it is necessary to use optimal bone replacement therapy\textsuperscript{3}. However, many traumatic and also non-traumatic bone injuries require treatment with bone substitutes or with grafts, depending on the extent of the defect and the loss of bone volume\textsuperscript{4,5

One approach for the treatment of traumatic bone damage is to transplant a bone graft, which may be of autologous, allogeneic or xenogeneic origin\textsuperscript{6}. This method is necessary to maintain the patient’s quality of life, and it is mainly used for treating disorders accompanied by a bone volume loss, e.g. due to non-union as a result of bone fractures, removal of bone neoplasm, osteomyelitis, osteonecrosis, cyst formation, etc. An os ilium bone graft has been considered as the “gold standard”, but the use of bone tissue from an allogeneic donor is ten times more common than the use of an autologous graft\textsuperscript{6}. These classical operations are often associated with graft problems, donor morbidity, low graft availability, and, in the case of allogeneic grafts, with the risk of disease transmission and an undesirable immunological response of the organism\textsuperscript{7,8

Synthetic grafts and implants, made of a variety of metallic, ceramic and polymer-based materials, are currently successfully used, but they also have limitations that lead to implant failure and to the need to reoperate\textsuperscript{9,10}. Biomaterials used for bone implantation should meet high requirements, such as long-term material durability, biocompatibility, corrosion and wear resistance, and biomechanical compatibility\textsuperscript{9}. Implants for replacing missing or damaged bones, or for interconnecting bone fragments, must not only be mechanically resistant, but must also quickly integrate with the host organism and must perform their functions as soon as possible and for as long as possible\textsuperscript{11}

A biomaterial is defined as any organic or inorganic material used in medical devices interacting with biological systems in order to treat, enhance or replace any tissue, organ or function of the human body. Several materials are used for implantation into the human body, namely various types of metals (non-corrosive steel, cobalt alloys, titanium alloys), ceramics (alumina, zirconium, calcium phosphate), and natural or synthetic polymers\textsuperscript{9}. After a biomaterial has been implanted into the patient’s body, there are mutual interactions of the two sys-