Chapter 12

Bio-Piezoelectric Ceramic Coatings for Bone Tissue Engineering Applications

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ABSTRACT

This chapter is focused on describing the latest advances related to the development of bio-piezoelectric coatings for bone regeneration applications. It starts with the description of the main concepts about bioelectrical phenomena in the human body and its role in the regeneration of bone. It explains concepts such as dielectric and electrical responses that includes piezoelectricity, pyroelectricity, and ferroelectricity and how the human bone can present these types of phenomena. The chapter also includes the definition of bio-ceramic materials and bioactive coatings, and a summary of the main bio-ceramic coatings employed nowadays for applications in bone tissue regeneration. Also, this chapter includes a review of the latest advances in the development of bio-piezoelectric coatings for bone tissue engineering and future

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perspectives on this topic. Overall, this chapter is focused on reviewing comprehensively the electrical response of natural tissues and the relevance of bio-piezoelectric ceramics for bone tissue regeneration.

1. INTRODUCTION

Tissue engineering is a field of biological engineering that works with biomaterials, combining scaffolds, coatings, cells, and molecules to promote the development of functional tissues. The purpose of tissue engineering is to create the conditions to restore and repair damaged tissues in the human body. This book chapter will review the main concepts related to bone tissue engineering, particularly those associated with the electrical stimulation of implanted materials that, according to normal biological processes of human bone, are able to remodel and solve local issues associated with the deterioration of hard tissues. In this section, piezoelectricity and how it appears in the human body will be introduced. In the following sections, further details about piezoelectricity and other properties of bone as well as the latest advances in biomaterials and coatings for hard tissue regeneration will be reviewed.

1.1 Piezoelectricity

Piezoelectricity was discovered in the 19^{th} Century by Jacques and Pierre Curie (Khorsand Zak et al. 2024). They found that when a stress was applied to different materials such as sugar cane, topaz, quartz, Rochelle salt, and tourmaline, electrical charges were produced at their surface with the resultant voltage being proportional to the applied load (Thomas et al 2018). The first application of this principle occurred several decades later during World War II with the development of sonar technology employed for detecting submarines and icebergs. From that moment, a great deal of attention was given to the development of new piezoelectric materials for different applications. From a crystallography perspective, the principle of piezoelectricity obeys the asymmetry of crystal structures or molecular chains (Xu et al. 2021). When ions of different charges are asymmetrically arranged in a piezoelectric crystalline material, the formation of electric dipoles occurs. Such misalignment can be produced by the application of an external mechanical strain in compression, tension, or bending. When the dipoles are formed the polarization of the base material occurs in the stress direction (Chorsi et al. 2019; Wu, 2024) and superficial free charges are released to generate piezoelectricity. This phenomenon is known as the direct piezoelectric effect. On the other hand, when an external electrical field is applied to a piezoelectric material a deformation proportional to the electrical field is produced, this is known as the converse piezoelectric effect. The linear interaction between the electrical and mechanical states in piezoelectric materials is described by a constant of proportionality, d, which is known as the piezoelectric coefficient. There are three parameters which are relevant to describe the performance of piezoelectric materials: i) the piezoelectric coefficient which is normally expressed as d_{xy}, where x indicates the direction at which the electrical field is applied or produced and y the direction of the applied stress or resulting strain; ii) the electromechanical coupling coefficient (K) which represents the mechanical and electrical energies involved to complete the piezoelectric transformation; and iii) the mechanical quality factor (Q_m) which

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