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Original Research Article

Computer engineering in designing and fabrication of tissue analogue-type coating dedicated for the cardiovascular regeneration

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ABSTRACT

The work was related to the development of novel methods in designing and fabrication of thin, porous, tissue-like coatings. The surface modification was designed to create an environment for the appropriate cell growth. The originally designed system was established to prepare porous, synthetic coatings. The dedicated software was elaborated to control the sequential coating deposition based on the electrostatic interaction. The finite elements method (FEM) was used to determine structural and mechanical properties of the coatings. The numerical model was verified experimentally. The performed simulation predicted the coating stabilization by the graphene nanoparticles. Graphene was introduced as a stabilizer of the polymer coating. The elaborated automatic system allowed preparation the porous coatings, repetitively. Coatings were stabilized by the cross-linking chemical reaction using 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide and N-hydroxysuccinimide. Nanoparticles were introduced by means of the electrostatic interaction. Mechanical analysis revealed an influence of the porous structure modification on the coating stiffness. Dynamic tests on blood subjected to the aortic flow showed antithrombogenic properties of the elaborated coatings.

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1. Introduction

Automation and repeatability of the process in designing and manufacturing of biomedical materials is a key issue in bioengineering. Precise mechanical systems controlled with the highly specialized, original software allow to save time as well as to fabricate materials in a repeatable way. The other issue associated with computer engineering in the presented study was application of the finite element method to design and simulate the properties of the porous coating. Before the material preparation, a theoretical model was elaborated. Till now, several theoretical approaches have been performed concerning different physical properties [1]. Manning and Ray presented new analysis and proofs [2]. They developed an expression for the Gibbs energy of aqueous polyelectrolyte solutions that contained contribution of electrostatic interactions occurring between charges on the polyion and counter ions. The other reports included the excess of Gibbs energy, like the model of Nagvekar and Danner [3], and the lattice theory model of Hao and Harvey [4]. Nordmeier [5–7] developed a counter ion association model, in which a polyelectrolyte was approximated by a linear array of fixed univalent point charges separated by a specific distance.

Due to small amounts of materials obtained using the layer-by-layer (LBL) technique there are difficulties in measuring of mechanical properties in-plane and through thickness of polymer composite films using conventional testing techniques, such as tensile and compression tests [8]. The nano-indentation technique [9] should provide an alternative approach to measure properties of small amounts of materials. Methods for measuring the Young's modulus have been very well established in Oliver and Pharr [9] method. The method is based on the Sneddon's solution [8] for the relationship between the load and displacement for an axisymmetric indenter. The nano-indentation is increasingly utilized to estimate the mechanical properties of polymeric films in the nanometer-scale thickness. Applications of such films is ranging from bioengineering via synthetic cell substrate [10–12] to insulating layers in integrated circuits [13]. In the context of biological applications, the mechanical compliance of these nanoscale films affects cell functions in a scale from cellular differentiation to cellular proliferation and even to apoptosis.

The other scientific aspect of the bioengineered material which was analyzed in the work, considered the blood–material interaction [14] causing thrombosis [15,16] and inflammatory reactions. Unfortunately, a truly non-thrombogenic surface does not exist. Thus, a surface modification plays a crucial role. The work exhibits aspects of the mechanics and biology in materials with polymer coatings. It is focused on elaboration of a mechanical system basing on a bio-robot for an automatic and repetitive deposition of porous polymer coatings which are dedicated to the cardiovascular devices. The main purpose of the work was to applied numerical methods for the effective novel coating both for designing and fabrication. The work considered two approaches, i.e. the software preparation for the automatic system control and the finite element method for the properties simulation of the elaborated porous coatings.

The target of the work was to produce porous polymeric structures in numerically controlled process, with prediction of their mechanical properties using the finite element method and finally a practical verification. The operating system was originally designed and built to deposit the coating extracellular-like matrix. The software was prepared for a need in the laboratory scale.

2. Materials and methods

The work considered three approaches: firstly, production of porous polymeric structures in automatic numerically controlled process; secondly, finite element methods application for the mechanical properties prediction; and finally experimental verification.

2.1. *Idea and construction of the system for the porous thin films deposition*

The porous coating deposition method is based on electrostatic interactions of two oppositely charged polyelectrolyte solutions [17,18]. For this purpose the automatic system (bio-robot) for the polymer coating deposition has been designed and elaborated. Fig. 1 presents the blueprint of the automatic system for the porous, extracellular-like coating deposition. Images of the real equipment originally designed and elaborated are presented in Fig. 2.

2.2. *Calculations used for the controlled and repetitive thin porous coating deposition*

The elaborated automatic system for the polymer coating deposition was under control of the originally written software responsible for the communication between the bio-robot and computer [19,20]. The program was dedicated especially to control its movements. The information related to the way of movement and time of the porous, synthetic coating elaboration was sent as a sequence of bits (SDU Serial Data Unit), from computer's USB port to FT232RL component (Future Technology Devices International Limited). FT232RL is an interface which convert the information to UART (Universal Asynchronous Receiver and Transmitter) form. Subsequently, the signal was translated from parallel to serial form by FT232RL interface and sent to microcontroller ATmega16. The ATmega16 is a low-power CMOS (Complementary Metal–Oxide–Semiconductor) 8-bit microcontroller based on AVR (Automatic Voltage Regulator) enhanced by RISC (Reduced Instruction Set Computing) architecture. It provided 16 Kb of In-System Programmable Flash Program memory and highly-flexible and cost-effective solution for the process control. The ATmega16 AVR was supported by the C compiler tool. The commands that have been written separated the single bits from the achieved information and translated them to high or low signals, depending on the need, which controlled the functioning of the engines responsible for the movements of the bio-robot arms. The microcontroller was responsible for manipulation via three-axis, micro-step driver STC102 manufactured by WObit company. The controller STC102 and device created consisted of two independent systems operated