Russian Journal of Biomechanics, Vol. 4, № 4: 37-43, 2000

Russian
Journal
of Biomechanics
www.biomech.ac.ru

CELL AND BIOPOLYMER BIOMECHANICS AND INTERACTIONS WITH POROUS SYSTEMS

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Abstract. The present paper has aim to show the effects of biomechanical properties of cells, biopolymers and the carrier structure on the efficiency of creating the bioactive composite materials. These materials are formed on the base of interaction of cells and biopolymers with carrier matrix. The cells in porous media may be immobilised by mechanical interaction with matrix in conditionally «static» (migration by capillary forces) or dynamic (filtration) regimes. For biopolymers the mechanism of interaction with matrix material is other (quasi-stationary flow of biopolymer solutions in porous media).

Key words: erythrocyte, bacterium, biopolymer, porous system, carrier strucrure

The processes of static and dynamic contacts of the biological objects (cells and biopolymers) with heterogeneous continua are not investigated enough. However the finest biotechnological applications may be realised only by biologically active composites. The typical examples of such kind of composites are 1) polymer carriers for immunochromatography (antigens immobilised on a polymer matrix and antibodies migrating to antigen zone); note that the use of porous carriers for immunochemical system gives the possibility of quick and quantitative separation to create new ELISA systems [1]; 2) antimicrobial materials having bactericide agents on fibre polymer surfaces [2]; 3) biosensor materials, i.e. polymer films with immobilised biomarkers [3]; 4) polymer matrix composites with implanted bioactive ingredients, in particular the drugs [4].

However cells and biopolymers can be immobilised on a polymer matrix by mechanisms of different nature.

The cells in porous media may by immobilised by mechanical interaction with matrix in conditionally «static» (migration by capillary forces) or dynamic (filtration) regimes.

Microfiltration plays an important role as one of the methods of biological cells investigation. For example, the microfiltration methods made possible to study the dynamics of antibiotic absorption by phagocytes at the initial stage of the cells contacts with morphocycline, tetracycline and methacycline [5].

Valuable and important diagnostic information on state of erythrocytes can be obtained by studying the speed of erythrocyte suspensions during passage across the microfiltration films [6].

Analysis of literature data concerning shape of erythrocytes and filterability of red cell suspension showed that both qualitative and quantitative changes of erythrocyte shape are important for erythrocyte deformability. One of the important quantitative factors of erythrocyte shape is negative curvature of the erythrocyte central part. The lowering of optical

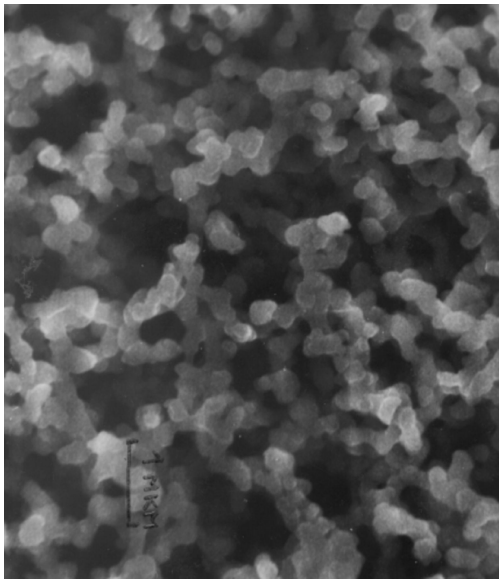

Fig. 1. Filter with the cellular structure. The scanner electron microscopy [10].

density gradient of the erythrocyte central part is connected with decrease of erythrocyte ability for deformation [7].

Many pathological processes are accompanied by pronounced disturbances of the blood circulatory system. At the same time new data on the importance of erythrocytes deformability changes due to hemorheological disturbances are accumulated (atherosclerosis, myocardial ischemia, purulent-septic diseases purulent inflammations) [8]. An importance of red cell deformability for blood rheology was shown along with plasma viscosity, hematocrit, and erythrocyte aggregation [6, 7].

Bessis and Mohandas [7] have investigated a deformability of normal, shape–altered and pathological erythrocytes and have shown that only the discocyte shape is capable of normal deformability. However their results are concerned only qualitative changes of shape but not quantitative changes.

In parallel with the erythrocyte form, the porous form of polymer carrier is also significant for filtration speed during contact with porous matrix.

Analysis of literature data has shown that the porous materials have different space organisation (structure). For example, in case of comparison of erythrocyte shape with experimental estimations of filterability of red cell suspension in patients with burns (in particular, thermal burns) the filter with cellular structure was used [9] (Fig. 1).

In paper [9] a connection between quantitative parameters of erythrocyte form (namely, gradient of optical density of the erythrocyte central part) and red cell filterability was observed.

The filters with different structure were employed [9-11]. The filter with structure of mutually joined spheres turned out to be more sensitive to change of erythrocyte form and decrease of filterability. The separate zones of such filter imitated the blood network parts of the «precapillar - capillar - postcapillar» type [8].

In a similar manner cholesterosis was experimentally investigated in rabbits [10], therewith the filter had mainly net structure (Fig. 2).

Trace filter (nuclepore) was employed in [11]. Time which a erythrocyte moves via pores is increased by the osmotic volume increase and decrease of deformability (Fig. 3).

When the nickel-mesh filter was employed [12] this time is influenced by the suspending medium viscosity and composition. Media, which induce erythrocyte aggregation,

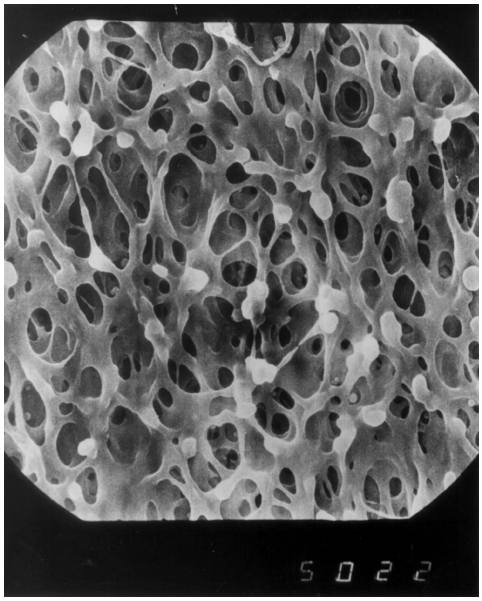

Fig. 2. Filter with the net structure. The scanner electron microscopy [10].

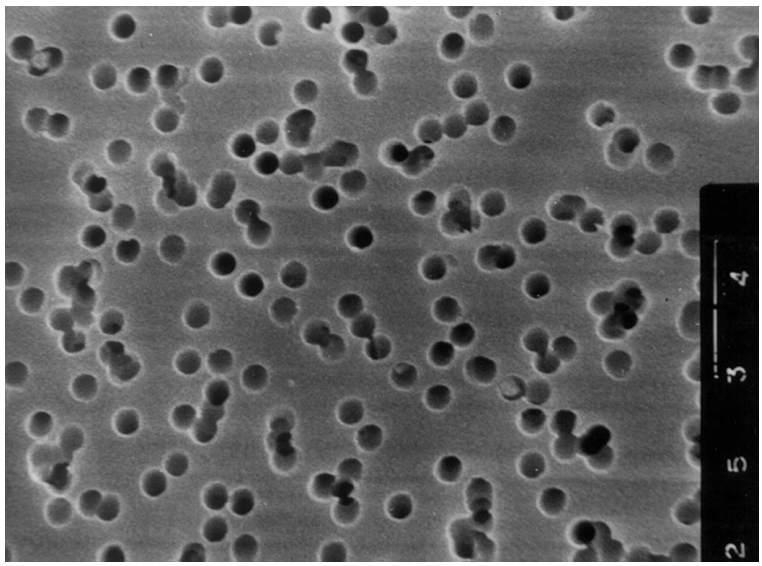

Fig. 3. Trace filter (the structure of disconnected cylindrical pores). The scanner electron microscopy [10].

encourage increase of time of erythrocyte movement via pores in comparison with dextran solutions of the same viscosity.

The quantitative estimation of deformability of erythrocyte shape was conducted by means of a «Diamorph» complex, i.e. the «microscope – computer» complex developed by Institute of Physico-Chemical Medicine, Russia [10]. The possibilities of this complex were earlier shown in diagnosis of the hyperlipoproteidemia [13]. One of the important factors of erythrocyte form is negative curvature of the erythrocyte central part. This fact was showed by morphodensitometry [13]. The decrease of optical density gradient of the erythrocyte central region is connected with decrease of erythrocyte ability for deformation (Fig. 4).

The pictures of erythrocyte deformation in porous materials have also a methodological significance. This is the reason why we consider erythrocytes as basic cells among all biological cells. In it we follow Akkerman [14], who took the membrane erythrocyte fastness as a standard.

The form of pore dictates the form of diskocyte, i.e. the cell with negative curvature of the central part. However bacterium has no its capsule sections with negative curvature of

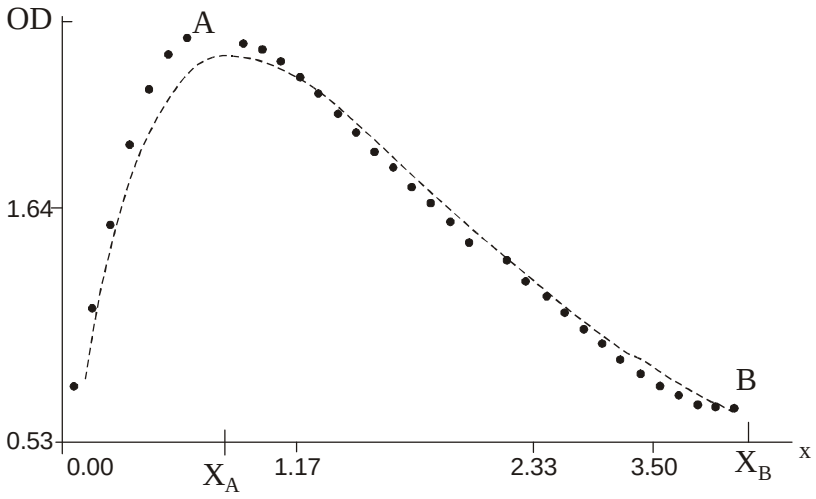

Fig. 4. Approximation of profile of diskocyte (1/4 of red cell) [13]. The negative curvature of erythrocyte central region (A-B) is an important characteristic of red cell shape.

central part shape in contrast to erythrocyte. In connection with this bacterium was supposed to be undeformed a priori [15].

Microfiltration is a promising trend in biotechnology which includes the concentration, purification, and separation of microorganisms. Scanner microscopy was used to examine microorganisms and to analyse their forms and dimensions as factors that determine the efficiency of filtration separation of cell suspensions [16]. So, the interactions with porous systems is a problem of biomechanics of a bacterial cell.

The problem of bacterial deformability by microfiltration was analysed by Kivman and Kalamova in [17], but their results are not simple.

The basic morpho-functional cell parameters were considered in aspect of cell biomechanics by Tairbekov and Regirer [18].

Lighthill in 1896 gave his original insight into microbiologic propulsion at very low Reynolds numbers. This Lighthill's view of microbiologic fluid mechanics was developed by others [19].

In paper [20] it was shown little difference between two cases when diffusion dominates, but substantial differences arise when convection is important.

In paper [21] bacterial transport at low Reynolds numbers was considered.

However these works [19-21] do not connect a bacterial behaviour with its contacts with porous materials.

In [16] microfiltration was considered to be a process of immobilisation of biological objects in porous system; it allowed to prognosticate the effectiveness of bacterial extraction [22].

For biopolymers, mechanisms of interaction with matrix material may be other.

The quasi-stationary flow of biopolymer solutions in porous media is very important for express impregnation tests to identifying the presence of some proteins in biological liquids. It was shown that the imbibition velocity depends on pore dimensions of nitrato–cellulose carrier with net and cellular structures, initial contact angle, percolation parameters, liquid surface and viscosity. The experimental data correlate well with the Lucas-Washburn equation [23, 24].

Apparently, in these cases disperse (colloidal) system of biological nature is co-operated with disperse (colloidal) system generated from polymer. Part of them is generated with condensing formation of structure; one of such processes is phase inversion of homogeneous polymeric solutions under influence of nonsolvent. This process allows to receive the porous membranes which have the given characteristics under various conditions -

a concentration of polymer in solution, content and temperature the bath. It gives the base for analysis of bacterial suspension movement in porous media [25].

The parameters of cell suspensions dictate increased requirements to the quantitative characteristics of a porous film, formed during phase division [25]. For example, an optimum combination of efficiency of bacterial elimination from a solution and filtration speed require the structure of a film to be net. One of the models describing a net structure was based on a universal volumetric representative element - hole sphere, and allowed to formulate the requirements to a porous film received from a polymeric solution. The next step was creation of the program allowing to estimate form and dimension of porous elements in membrane cross-sections. Such received porous films have known biomechanical characteristics. For example, the samples of membranes with diameters of pores of 0.4 micron held bacterium with a rigid wall and minimal size of 0.3 micron; it is predicted by the program when analysing a lattice in cross-sections.

All types of structure can be mathematical modelled [26]. The models of carrier structures gives possibility to elaborate the model of cell deformation [27, 28].

Conclusion

The present paper has aim to show the effects of biomechanical properties of cells, biopolymers and the carrier structure on the efficiency of creating the bioactive composite materials. These materials are formed on the base of interaction of cells and biopolymers with carrier matrix.

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Russian Journal of Biomechanics, Vol. 4, № 4: 37-43, 2000

БИОМЕХАНИКА КЛЕТОК И БИОПОЛИМЕРОВ И ИХ ВЗАИМОДЕЙСТВИЕ С ПОРИСТЫМИ СИСТЕМАМИ

Г.Н. Ковалев, Н.С. Снегирева, Е.И. Шафранова (Москва, Россия)

Настоящая статья посвящена анализу влияния биомеханических свойств клеток и биополимеров, а также структуры носителей (пористых полимерных пленок) на процессы создания биоактивных композиционных материалов. Эти материалы формируются на основе взаимодействия клеток и биополимеров с матрицей носителя. Эффективность работы этих материалов в аналитических системах зависит от полноты контакта биологических объектов с матрицей пористого материала. Механизмами иммобилизации клеток являются статические и динамические режимы взаимодействия с пористыми средами. Для биополимеров иммобилизация реализуется на основе квазистационарного процесса вязкого течения раствора биополимера в структурированной среде. Библ. 28.

Ключевые слова: эритроцит, бактерия, пористая система, носитель

Received 3 November 2000