MATHEMATICAL MODEL OF DYNAMIC ADHESION OF LYMPHOCYTES ON A GLASS-BEAD COLUMN

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A mathematical description of the process of adherence to glass of the rat thymus lymphocytes is presented. It is based on the result of previous work in which the process was studied in the course of the flow of the $^{51}$Cr labelled cell suspension through the glass-bead column. The concentration of cell suspension, flow velocity and medium temperature were constant; the experiments were performed with different lengths of the bead bed. The amount of cells captured on the glass beads' surface was calculated as a function of time. Two approaches to the mathematical description of the process are presented. The first one is based on the linear equation of kinetics of cell retention on the elementary thin layer and on the transport equation of the flow of the suspension through the column. In the second one, the differential equation of the adhesion, derived from the experimental data, is discussed.

Investigation of phenomena associated with the retention of cells in model structures simulating certain traits of the microcirculation network, in the course of cell flow through channels of this system, is important for two reasons. On the one hand, processes playing an important role in the life cycle of cells circulating in the blood and lymph, particularly as regards various functions of organs and tissues such as lungs, spleen, lymphatic nodes and others are involved. Model studies, on the other hand, may contribute to a better knowledge of physical and physico-chemical phenomena which lie at the basis of processes of cell adhesion, passing of cells through narrow vessels, interaction between cells, etc. Various lines of research in these domains of high significance are, among others, trials of mathematical description of the behaviour of cells in various parts of the vascular network in model systems.

The present paper is an attempt at a quantitative analysis of the phenomenon of lymphocyte adhesion in the course of the flow of a cell suspension
through a column of glass beads. The works of other authors concerning the biophysical aspects of cell adhesion mainly deal with the energy of interaction between the cells or between cells and the substrate, in connection with the DLVO theory (Curtis, 1967; Weiss, 1972). Some papers have been devoted to mathematical analysis of the structure of certain physical systems (bead layer) utilized in investigations of cell adhesion (Blumenson, 1967). Interesting analogies as regards phenomena of colmatage may be found in studies from the field of geology (Trzaska, 1972).

The present paper concerns dynamic lymphocyte adhesion which was the subject of previous studies (Kowalczyńska et al., 1973) including also the adhesion of red blood cells under similar conditions. Quantitative analysis of the interaction between lymphocytes and the substrate is important in view of a number of problems concerning the physiological role and kinetics of these cells in vivo (Doroszewski et al., 1968; Senator et al., 1970; Skierski, 1974), and in connection with the adhesion method for separation of lymphocytes T and B (Adams, 1973). It seems, moreover, that the mathematical model of dynamic adhesion of one type of cells (lymphocytes) may prove useful also as starting point for quantitative description of analogous phenomena involving other cell populations.

I. The method applied in the present work for investigation of dynamic lymphocyte adhesion has been described in detail in the preceding paper (Kowalczyńska et al., 1973); it may be summarized as follows.

Lymphocytes of the rat thymus labeled with $^{51}$Cr are suspended in a phosphate-buffered solution (PBS, without protein). The cell suspension passes (flow being forced with a peristaltic pump) through a glass column filled partly with soda-glass beads 300-400 μm in diameter. The concentration of the cells flowing into the column is $4 \times 10^6 (\pm 10)$ cells/ml. The volume velocity of flow is 2.3 ml/min. Temperature inside the column is maintained at $37 \pm 0.2^\circ$C. The pH of the medium used for the perfusion was 7.0-7.2 both before and after flow through the column. The experiments were performed with five different lengths of the bead bed (1.2, 1.6, 2.0, 2.4 and 2.8 cm). By measurement of $^{51}$Cr activity the concentration of the cells flowing out of the column in a definite time interval was determined and the fraction of cells retained on the bead bed was calculated as a function of the duration of perfusion. For elaboration of results the mean values of six (for bed length 1.2 cm) or of four (for remaining lengths) experiments were taken.

The results of experiments can be summarized as follows. The cell concentration in the suspension flowing out from the bead bed at the beginning of perfusion is low. It slowly increases and reaches, towards the end of the experiment, a value close to the concentration in the inflowing suspension. Thus, the number of cells retained on the bead bed increases with the duration of per-