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# PPLATE: a computer program for analysis of parallel-plate flow chamber experimental data

Yi Zhang, Sriram Neelamegham*

*Bioengineering Laboratory, Department of Chemical Engineering, 906 Furnas Hall, State University of New York at Buffalo, Buffalo, NY 14260, USA*

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## 1. Introduction

PPLATE is a computer program developed to analyze raw cell adhesion data obtained from the parallel-plate flow chamber. It is based on a mathematical model described elsewhere (Zhang and Neelamegham, 2002a). The objective of this software is to analyze raw data on cell rolling, firm-arrest and cell transmigration to determine four frequency and probability parameters, namely, primary capture frequency, firm-arrest frequency, cell–cell capture probability and rolling-release frequency. These parameters are analogous to the ‘‘adhesion efficiency’’ used to quantify the rate of cellular aggregation in suspension. Overall, while the raw cell rolling and firm-arrest data are a function of the physical features of the experiment system that control the rate of cell–substrate and cell–cell collisions such as inlet cell concentration and wall shear stress, the frequency and probability parameters are purely functions of the biological adhesivity of cells and their response to fluid shear forces. The program could find application in diverse research areas that use the flow chamber device including studies of leukocyte–endothelium interaction, platelet adhesion at sites of vascular injury, bacterial adhesion under fluid flow and cancer metastasis.

## 2. Description

The parallel-plate flow chamber is used to study cell surface adhesion molecule function and receptor–ligand binding biophysics under physiologically relevant hydrodynamic flow conditions (Gopalan et al., 1997; Goetz et al., 1999). Typical experiments quantify the interaction between the cells in suspension and the ligand-bearing flow chamber substrate in terms of: (i) rolling cell density, (ii) adhesion cell density and (iii) cell transmigration rate. Besides the biological properties of the cells, the physical features of the system that control the number of cell–substrate and cell–cell collisions also influence these three measures. These physical features include, but are not limited to, the flow chamber size, wall shear stress, cell dimension and density, media density and inlet cell concentration.

* Corresponding author. Tel.: +1-716-645-2911x2220; fax: +1-716-645-3822.

*E-mail address:* neel@eng.buffalo.edu (S. Neelamegham).


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The program, PPLATE, is developed with the objective of separating the effects of the physical features of the system listed above from the biological feature that control cellular adhesivity. It is based on a mathematical model described elsewhere (Zhang and Neelamegham, 2002a,b). The objective of the model is to quantify four adhesion frequency and probability parameters for any given experimental condition. These parameters are: (i) primary capture frequency, (ii) cell–cell capture probability, (iii) firm-arrest frequency and (iv) rolling-release frequency. These parameters are purely measures of the cellular adhesivity. While primary capture frequency quantifies the rate at which cells in the free stream initiate rolling, the firm-arrest frequency is a measure of the rate of transition from rolling to firm-binding. The cell–cell capture probability quantifies the probability that cells in the free stream adhere onto the substrate following collision with previously recruited cells. Finally, the rolling-release frequency quantifies the reversible release of cells from rolling back into the free stream.

During each program run, the user is required to set the inlet cell concentration and applied shear rate. Following this, the user must decide to vary two of the following variables/parameters over a defined range while keeping the remaining constant: dimensionless position $x^*$, simulation time $t$, primary capture frequency $\theta_{fr}$, firm-arrest frequency $\theta_{ra}$, cell–cell capture probability $\theta_{cc}$, rolling-release frequency $\theta_{rf}$, and transmigration time $t_{TM}$. The reason why only two of the parameters are varied is because this allows convenient presentation of simulation results in the form of a two-dimensional matrix. The physical features of the system, like the description of cell and media attributes, and the flow chamber dimension are set to the default values listed in Table 1 of Zhang and Neelamegham (2002a). For a user with a flow chamber of different size or using cells with other dimensions, the default values can be readily varied by changing the parameters in the data file DATA.TXT, which accompanies the software. This file can be saved in text format using any software. The simulations performed here are not time-consuming, and it only takes ~ 10–15 s to simulate a 10-min flow chamber run on a 366-MHz Pentium PC. We note that the run times may vary depending on the nature of the simulation parameters chosen.

Simulation result was written into output file in text format. They can be read into many softwares including Microsoft Excel and Notepad. The output file lists the default system parameters and adhesion frequencies used in this run. This list of simulation parameters is followed by 3 two-dimensional data tables with the simulation results for: (i) rolling cell density, (ii) firmly adherent cell density and (iii) total transmigrated cell density. Comparison of experimental data with simulation results allows estimation of the four frequency parameters for the given run as discussed elsewhere (Zhang and Neelamegham, 2002a).

## 3. Hardware/software requirements

The program is written in Digital Visual Fortran version 6.0 for IBM PC and compatibles. Recompilation of the code requires linkage to the IMSL Numerical Library (Visual Numerics, San Ramon, CA). The executable version of the code (PPLATE.EXE) has been tested on PCs running Windows operating system. Recompilation of the program on other operating systems (MacOS, UNIX) should also result in flawless execution of the code.

## 4. Availability

The main program, PPLATE.EXE, is available from the journal's software archive (http://jim.mscs.mu.edu) under the directory pub/zhang via anonymous FTP. The FORTRAN source file PPLATE.FOR, input data file DATA.TXT, a word document containing sample program inputs (INPUT.DOC) and three sample output files that test the program under different conditions (RUN01.TXT, RUN02.TXT and RUN03.TXT) are also provided. We note that it is necessary that the file DATA.TXT be placed in the same directory as PPLATE.EXE during execution of the program. The output has been formatted for use/manipulation by the speadsheet software Microsoft Excel. The output file is best opened by using the space-delimited feature of this software. The full manuscript describing the equations used in the software is published (Zhang and Neelamegham, 2002a). Copies of the program can also be obtained from: http://www.eng. buffalo.edu/~neel/pplate.

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