Red Blood Cell Dielectrophoresis in Axisymmetric Fields

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ABSTRACT

Dielectrophoretic velocities of human red blood cells in an axisymmetric field were measured as a function of the applied voltage and the distance from the axis of symmetry. The voltage of the alternating electric field (frequency 2 MHz), applied between two concentric cylindrical metal electrodes (outer and inner radii 0.24 and 1 mm, respectively), was varied up to 19 V. Two kinds of mediums were used: (a) 90% of 2.1% glycine solution and 10% of 5.5% glucose solution and (b) 5.4% sorbitol solution. The results have shown that in both mediums the cell velocities are proportional to the square of the applied voltage and inversely proportional to the cube of the distance from the axis of symmetry, as predicted by the theory. The coefficient of proportionality (dielectrophoretic coefficient) is on the order of $10^{-25}$ A$^2$s$^4$kg$^{-1}$. It depends on the donor of red blood cells and might be used for diagnostic purposes. These results will be used in future investigations of membrane adhesion, stability and fusion.

Index Entries: Cell dielectrophoresis; red blood cells; cell polarization; dielectrophoretic velocity; axisymmetric alternating electric fields; membrane adhesion; membrane fusion; membrane stability.

INTRODUCTION

Motion of polarizable particles in nonuniform electric fields, called dielectrophoresis (1), has many applications in biological research (1).

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One important example is developing of cell fusion techniques, where the cells are brought at close approach by applying alternating nonuniform electric fields and fused after application of short electric pulses of high intensity [see, e.g., the review (2)].

Dielectrophoresis in axisymmetric fields has the basic advantage that the electric field intensity distribution can be easily calculated theoretically and compared with experimentally observed particle velocities. Recently, we have constructed a device, especially designed for comparative investigations of dielectrophoretic force with applications to membrane adhesion, stability, and fusion, where a nonuniform electric field is created between two concentric cylindrical electrodes (3).

The basic idea has been to measure the dielectrophoretic velocities and by knowing the distribution of the electrical field to calculate the dielectrophoretic force. On the one hand, assuming that the dielectric properties of the cell and the medium do not change significantly when the cell approaches the central electrode, we can assume that the dielectrophoretic force will follow the theoretical dependence at very close separations of the cell from the electrode. On the other hand, we have presented a formula for the rate of approach of the cell to the electrode, valid for arbitrary separations and deformable cells (4,5). In this way, based on experimental observations of the dielectrophoretic velocity at large distances from the electrode, we can predict the rate of approach at close separations, i.e., the kinetics of dielectrophoretically induced cell adhesion. In addition, the radius of contact of the cell to the electrode can be calculated and compared with experimental observations. The possible difference between the calculated and observed contact area will indicate effects of close approach on the dielectric properties of the cell.

The basic goal of this work is to provide experimental data on dielectrophoretic velocities of red blood cells at relatively large separations and to check the theoretical predictions for the dependence of the velocity on the distance from the electrode and the applied voltage. These data can also indicate for differences in dielectric properties of different types of red blood cells and suggest a method for characterization of the effective cell polarization. The advantage of this method over some of the other methods for measuring effective dielectric properties of cells, e.g., by measuring the optical density of cell suspension (6), is that it operates with single cells and has quantitative theoretical basis.

In the next sections we present the theoretical background, the experimental methods and materials, the experimental results, and their discussion.

**THEORETICAL BACKGROUND**

The force, $F$, exerted on a particle by a nonuniform alternating electric field, depends on the field intensity $E$ and the dielectric and conductivity properties of the particle and the surrounding medium (1). For the