Cytoplasmic Streaming in *Paramecium*

J. SIKORA *

Department of Cell Biology, M. Nencki Institute of Experimental Biology, Warszawa

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Summary

Certain species of *Paramecium* demonstrate rotational cytoplasmic streaming, in which most cytoplasmic particles and organelles flow along permanent route, in a constant direction. By means of novel methods of immobilization, observation and recording, some dynamic properties of cytoplasmic streaming have been described. It was found that the velocity profiles of coaxial layers of cytoplasm have a (parabolic) paraboloidal shape and the mean output of cytoplasm flow in different examined zones of streaming is constant. As the consequence of randomly distributed elementary propulsion units within the cytoplasm, particles, which serve as markers of movement, exhibit movements of a saltatory nature; this form of movement is seen in *Paramecium* streaming only in cases of error due to polarization of the saltating particles. Interaction of actin filaments and myosin is likely to occur under specific conditions in microcompartments of cytoplasm where local solations are generated eventually leading to contractions which might propagate on gelated neighbouring areas. Places of elementary contractions are scattered. Therefore the motile effect appears as streaming. Rotational cytoplasmic streaming in *Paramecium* may serve as a convenient model for the study of the dynamics and function of cytoplasmic motility.

Keywords: Cytoplasmic streaming; Dynamic properties; *Paramecium*; Propulsion mechanism.

1. Introduction

In some cells cytoplasmic streaming is easily seen as a rather fast flow of relatively large masses of liquefied cytoplasm (see reviews by KAMIYA 1959, JAHN and BOVEE 1969, YAMADA 1969, KOMNICK *et al.* 1973, ALLEN and ALLEN 1978 a, b, SIKORA 1981 b). However most eucaryotic cells do not show movements of this character. Usually, movements are slow and can be detected and recorded only by a special time lapse cinematographic techniques.

In *Protozoa* the rotational cytoplasmic streaming has been described chiefly in the genus *Paramecium*. Cytoplasmic streaming has also been extensively described in several other species, such as amoebae. These cells share many

* Correspondence and Reprints: Department of Cell Biology, M. Nencki Institute of Experimental Biology, 3 Pasteura Str., 02-093 Warszawa, Poland.
features common to rotational streaming in Paramecium. Thus, because of its locomotive function and non-rotational character, the knowledge of this streaming has restricted application for understanding the physiological aspects of rotational streaming. Nevertheless it seems probable that the greatest differences between different cytoplasmic movements described so far depend chiefly on the velocity and the quantity of cytoplasm directly involved in the particular movement. Moreover the location of propelling structures is of far reaching importance. In this sense, the cytoplasmic streaming might be considered as one of the most dynamic forms of cytoplasmic motile activity. According to this suggestion, some translocations of the constituent subcellular organelles and other structures, in the whole cell cycle—especially in the period of differentiation—may be facilitated by this efficient intracellular transport system. The character of these movements seems to be related to the rotational cytoplasmic streaming in Paramecium (Sikora 1981 a).

Within the Paramecium, the cytoplasm flows constantly, in the same direction, forming a closed circuit. This movement takes place during most of the interfission period. Only in the time immediately preceding division of a Paramecium and in a definite phase of conjugation, the streaming ceases. Short periods of spontaneous cessation of streaming take place very rarely (Sikora and Kuźnicki 1973 a, 1975, 1976, Sikora 1976, 1981 b). In the period of restoration of the cytoplasmic streaming, the saltatory movements appear first, followed by circulatory motions and eventually the regular cytoplasmic streaming is restored (Kuźnicki and Sikora 1973 a, Sikora and Kuźnicki 1976). This is consistent with the suggestion that different forms of cytoplasmic movements may be transformed into each other (see reviews by Kamiya 1959, Hepler and Palevitz 1974, Allen and Allen 1978 b, Sikora 1981 b), also in the case of rotational cytoplasmic streaming in Paramecium (see Sikora 1976, Sikora and Kuźnicki 1976).

The fact that the cytoplasm in Paramecium and other cells can undergo dramatic functional changes raises a number of questions. Where do the propulsive mechanism of rotational cytoplasmic streaming come from? How do life cycle events and/or environmental agents induce or reduce this activity? Most importantly what is the functional role of the rotational streaming?

In an attempt to help further our knowledge of the mechanisms of rotational streaming, some of the main results obtained from Paramecium are reviewed in this article.

2. Progress in Techniques

2.1. Methods for Immobilization

Paramecia are almost constantly swimming. Only while feeding intensively, they become motionless, adhering with their cilia to the substratum