

Transport of Microscopic Objects Using Line Optical Tweezers: Manipulation of Neuronal Growth Cones

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The transport of microscopic objects plays an important role in several biophysical processes that are crucial for cell functioning. By becoming able to effect controlled transport of intracellular objects, researchers can not only understand these fundamental processes better but also manipulate the functionality of living cells.

We have shown that line optical tweezers, with an asymmetric intensity distribution along the major axis of the

elliptical trap beam, can be used for efficient and controlled transport of microscopic objects in a plane transverse to the direction of beam propagation.¹ The asymmetry in the intensity distribution of the trap beam about its center results in a potential well that is asymmetric about the center of the beam.

Thus, particles at the steep end of the potential well are pulled toward the potential minima, accelerate, and are ejected in the direction toward the lower stiffness. Since the gradient force is large and symmetric in the other two orthogonal directions, the particles are constrained to move along the major axis of the line tweezers.

We controlled the depth and the asymmetry of the potential well by a control on trap beam power and by a change in the angle of incidence of the laser beam with respect to the optic axis of the microscope objective. To change the direction of transport, we rotated the cylindrical lens to fix the direction of the major

axis of the elliptical focus at the desired angle in the transverse plane.

Irradiation of a neuron with this asymmetric intensity profile line tweezers could be used to increase the growth rate of the existing cones or even generate new ones.² To accelerate the growth rate of the existing cones, we brought the cell body of the neuron near the high intensity

gradient end of the elliptical focus such that the tip of the growing edge was closer to the lower gradient force. Since the neuronal growth is believed to involve transport of actins in the direction of the growth cone,³ the observed enhancement in growth can be attributed to diffusion of actins.

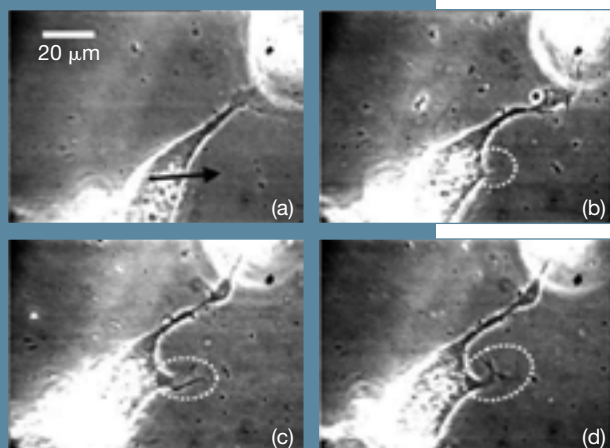
Compared to a growth rate of $1 \pm 1 \mu\text{m/h}$ observed for unexposed neurons, the lamellipodia extension rate in a neuron subjected to line tweezers was estimated to be $32 \pm 6 \mu\text{m/h}$. The asymmetric transverse gradient force could also be used for induction of new growth cones from the neuronal cell body (see figure). The optically induced growth cones showed branching similar to that observed in the natural process of growth.

However, the growth rate of these induced cones was lower ($15 \pm 3 \mu\text{m/h}$) than that achieved for natural growth cones. This approach could be used to change the orientation of a growth cone to bring it into close proximity with a cone of another neuron. The ability to exert such control on neuronal growth cones may prove useful for establishing a connection between two neurons. ▲

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Optical induction of new neuronal growth cone. A neuronal cell subjected to asymmetric intensity profile line tweezers (trap beam power 120 mW) in the direction marked by arrow (a). Induction of new growth cone (circled) after exposure time of 20 min (b), 25 min (c) and 45 min (d). Natural branching of induced growth cone can be observed in panel d.