

Coordination of Dynein Motor Enzymes for Generation of 3-dimensional Flagellar Bending Waves

Charles J. Brokaw
Division of Biology
California Institute of Technology
Pasadena, CA 91125
Brokawc@its.caltech.edu

ABSTRACT

Eukaryotic flagella contain tens of thousands of dynein motor enzymes, arranged in regular arrays along the outer doublet microtubules of the axoneme -- the internal cytoskeleton of a flagellum or cilium. These dyneins produce longitudinal sliding between the doublet microtubules. They must interact cooperatively to generate the bending waves that are required for efficient propulsion of spermatozoa, or other situations.

Sperm flagella can generate a variety of bending patterns, including nearly two dimensional patterns that can be approximated as planar bending waves and three-dimensional bending patterns that are approximately helical waves. In some situation, they can switch between these two types of bending [1,2].

Computer programs have been developed previously that can simulate planar flagellar bending waves, by assuming that bending can only occur in a two-dimensional world [3]. The key idea of these programs is local control of active sliding by the local curvature of the axoneme. Some of these programs have included individual dynein molecules [4]. In these programs, each dynein molecule is modelled stochastically, using kinetic equations based on ideas about the operation of muscle myosin, since we have little information about how dynein motor enzymes work.

A computer program for simulating flagellar bending in a three dimensional world is now being developed. Results show that local curvature control easily generates helical bending waves, without requiring any special coordination to control the propagation of activity around the circumference of the axoneme. Helical bending is the "line of least resistance", which allows each longitudinal row of dyneins to generate a propagated bending wave with minimum

interference from its neighbors. It may be analogous to the phenomenon of metachronal bending waves, commonly seen when large arrays of cilia interact on the surface of a ciliated epithelium.

With the three dimensional model, planar bending waves can be generated if the dyneins are forced to operate in two groups, one on each side of the axoneme. Each group is controlled by curvature, and operates as a unit. This is the first demonstration of two dimensional bending wave generation by a three dimensional flagellar model. However, it is not yet clear how this grouping could be overruled when a flagellum switches back to a helical pattern, as seen experimentally [1,2].

REFERENCES

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