

References

AIELLO, E. L. (1960). Factors affecting ciliary activity on the gill of the mussel *Mytilus edulis*. *Physiol. Zool.* **33**, 17-21.

BABA, S. A. (1975). Developmental changes in the pattern of ciliary response and the swimming behavior in some invertebrate larvae. In *Swimming and Flying in Nature*, vol. 1 (ed. T. T.-Y. Wu, C. J. Brokaw and C. Brennen), pp. 317- 323. New York: Plenum Press.

BABA, S. A. (1979). Regular steps in bending cilia during the effective stroke. *Nature* **282**, 717-720.

BABA, S. A. and MOGAMI, Y. (1987). High time- resolution analysis of transient bending patterns during ciliary responses following electric stimulation in sea urchin embryos. *Cell Motil. Cytoskeleton* **7**, 198-208.

BABA, S. A., INOMATA, S., OOYA, M., MOGAMI, Y. and IZUMI-KUROTANI, A. (1991). Three- dimensional recording and measurement of swimming paths of micro-organisms with two synchronized monochrome cameras. *Rev. Sci. Instrum.* **62**, 540-541.

BROKAW, C. J. (1991). Microtubule sliding in swimming sperm flagella: direct and indirect measurements on sea urchin and tunicate spermatozoa. *J. Cell Biol.* **114**, 1201-1215.

BROKAW, C. J. (1989). Direct measurements of sliding between outer doublet microtubules in swimming sperm flagella. *Science* **243**, 1593-1596

DEGAWA, M., MOGAMI, Y. and BABA, S. A. (1986). Developmental changes in Ca²⁺ sensitivity of sea urchin embryo cilia. *Comp. Biochem. Physiol.* **85A**, 83-90.

HAMASAKI, T., BARKALOW, K., RICHMOND, J. and SATIR, P. (1991). cAMP-stimulated phosphorylation of an axonemal polypeptide that copurifies with the 22S dynein arm regulates microtubule translocation velocity and swimming speed in *Paramecium*. *Proc. natu. Acad. Sci. U.S.A.* **88**, 7918-7922.

IMMERS, J. and LUNDGREN, B. (1972). Aspects of differentiation and function of cilia and adjacent structures of the sea urchin larva. *Acta embryol. exp.* **2**, 177-197.

KADAM, A. J. and KOIDE, S. S. (1990). Stimulation of *Spisula* sperm motility by 5-hydroxytryptamine analogs. *Invert. Reprod. Dev.* **17**, 33-37.

KINOSITA, H. (1954). Electric potentials and ciliary response in *Opalina*. *J. Fac. Sci. (Tokyo University)* **7**, 1-14.

LACALLI, T. C. and GILMOR, T. H. (1990). Ciliary reversal and locomotory control in the echinopluteus. *exp. Cell Res.* **72**, 115-139.

MACKIE, G. O., SPENCER, A. N. and STRATHMANN, R. (1969).
Electrical activity associated with ciliary reversal in an echinoderm larva. *Nature* **223**, 1384-1385.

McFADDEN, G.I., SCHULZE, D., SUREK, B., SALISBURY, J.L. and MELKONIAN, M. (1987). Basal body reorientation mediated by a Ca²⁺-modulated contractile protein. *J. Cell Biol.* **105**, 903-912.

MOGAMI, Y. and TAKAHASHI, K. (1983). Calcium and microtubule sliding in ciliary axonemes isolated from *Paramecium Caudatum*. *J. Cell. Sci.* **61**, 107-121.

MOGAMI, Y., OOBAYASHI, C., YAMAGUCHI, T., OGISO, Y. and BABA, S. A. (1988). Negative geotaxis in sea urchin larvae: a possible role of mechanoreception in the late stage of development. *J. exp. Biol.* **137**, 141-156.

MOGAMI, Y., PERNBERG, J. and MACHEMER, H. (1990). Messenger role of calcium in ciliary electromotor coupling: A reassessment. *Cell Calcium.* **11**, 665-673.

MOGAMI, Y., FUJIMA, K. and BABA, S. A. (1991). Five different states of ciliary activity in the epaulette of echinoplutei. *J. exp. Biol.* **155**, 65-75.

MOGAMI, Y., WATANABE, K., OOSHIMA, C., KAWANO, A. and BABA, S. A. (1992). Regulation of ciliary movement in sea urchin embryos: dopamine and 5-HT change the swimming behaviour. *Comp. Biochem. Physiol.* **110C**, 251-254.

MOGAMI, Y., SEKIGUCHI, S. and BABA, S. A. (1993). Beating of cilia of sea urchin embryos: a critical comparison of the normal and reversed beating of cilia of isolated cells. *J. exp. Biol.* **175**, 251-266.

NAITO, Y. and KANEKO, H. (1972). Reactivated triton-extracted models of *Paramecium*: Modification of ciliary motility by calcium ions. *Science* **176**, 523-524.

NAKAJIMA, Y. (1987). Localization of catecholaminergic nerves in larval echinoderms. *Zool. Sci.* **4**, 293-299.

OKAMOTO, K. and NAKAOKA, Y. (1994a). Reconstitution of metachronal waves in ciliated cortical sheets of *Paramecium*. I. Wave stabilities. *J. exp. Biol.* **192**, 61-72.

OKAMOTO, K. and NAKAOKA, Y. (1994b). Reconstitution of metachronal waves in ciliated cortical sheets of *Paramecium*. II. Asymmetry of the ciliary movements. *J. exp. Biol.* **192**, 73-81.

OMOTO, C. K. and KUNG, C. (1979). The pair of central tubules rotates during ciliary beat in *Paramecium*. *Nature* **279**, 532-534.

SALISBURY, J.L. and FLOYD, G. (1978). Calcium induced contraction of the rhizoplast of a quadriflagellate green alga. *Science* **202**, 975-978.

SATIR, P. (1968). Studies on cilia. III. Further studies of the cilium tip and a "sliding filament" model of ciliary motility. *J. Cell Biol.* **39**, 77-94.

SATIR, P. (1982). Mechanisms and controls of microtubule sliding in cilia. In *Prokaryotic and Eukaryotic Flagella*. (eds. W. B. Amos and J. G. Duckett), *Soc. exp. Biol. Symp.* **35**, pp. 179-201. Cambridge: Cambridge University Press.

SATIR, P. (1985). Switching mechanisms in the control of ciliary motility. *Modern Cell Biol.* **4**, 1-46.

SATIR, P. and SLEIGH, M. A. (1990). The physiology of cilia and mucociliary interactions. *A. Rev. Physiol.* **52**, 137-155.

SHINGYOJI, C., KATADA, J., TAKAHASHI, K. and GIBBONS, I. R. (1991). Rotating the plane of imposed vibration can rotate the plane of flagellar beating in sea-urchin sperm without twisting the axoneme. *J. Cell Sci.* **98**, 175-181.

SIMPSON, P.A. and DINGLE, A.D. (1971). Variable periodicity in the rhizoplast of *Naegleria* flagellates. *J. Cell Biol.* **51**, 323-328.

SPIEGEL, E. and HOWARD, L. (1983). Development of cell junctions in sea-urchin embryos. *J. Cell Sci.* **62**, 27-48.

STRATHMANN, R. R., JAHN, T.L. and FONSECA, J.R. (1972). Suspension feeding by marine invertebrate larvae: Clearance of particles by ciliated bands of a rotifer, pluteus, and trochophore. *Biol. Bull. Mar. biol. Lab., Woods Hole* **142**, 505-519.

STEPHENS, R. E. and PRIOR, G. (1992). Dynein from serotonin-activated cilia and flagella: extraction characteristics and distinct sites of cAMP-dependent protein phosphorylation. *J. Cell Sci.* **103**, 999-1012.

SUGINO, K. and MACHEMER, H. (1990). Depolarization-controlled parameters of the ciliary cycle and axonemal function. *Cell Motil. Cytoskeleton* **16**, 251-265.

SUGRUE, R., AVOLIO, J., SATIR, P. and HOLWILL, M. E. J. (1991). Computer modelling of Tetrahymena axonemes at macromolecular resolution. Interpretation of electron micrographs *J. Cell Sci.* **98**, 5-16.

TAMM, S. and HORRIDGE, G. A. (1970). The relation between the orientation of the central fibrils and the direction of beat in cilia of *Opalina*. *Proc. R. Soc. Lond.* **B 175**, 219-233.

TAMM, S. L. and TAMM S. (1981). Ciliary reversal without rotation of axonemal structures in ctenophore comb plates. *J. Cell Biol.* **89**, 495-509.

WAIS-STEIDER, J. and SATIR, P. (1979). Effect of vanadate on gill cilia: switching mechanism in ciliary beat. *J. supramolec. Struct.* **11**, 339-347.

Acknowledgment

I would like to thank Dr. Shoji A. Baba for giving many helpful advice, computer programming of calculating shear angles or curvatures and collecting my poor English.

I also would like to thank Dr. Yoshihiro Mogami for giving me technical advice and helpful suggestion to constructing the logic of this paper.

I thank Dr. Shin-ichi Nemoto who is a chief judge of examination committee of my paper. I thank Drs. Seki Shimizu, Sadao Ishiwa and Syuko Fujieda for judging my paper and giving me helpful comments.

I thank Tateyama marine laboratory of Ochanomizu University and Misaki marine laboratory of Tokyo University for providing fresh sea urchins.