binds to active tubulin is hydrolysed to GDP in association with tubulin assembly, but not necessarily at the time of subunit addition. The delay in hydrolysis results in a cap of GTP-tubulin whose length depends on the rate of polymerization. This suggests that polymer growth should normally be a balance between the rates of addition and falling off of GTP-tubulin, but if GTP hydrolysis should catch up with subunit addition, the situation would change. The GTP-tubulin cap would then be converted to a GDP-tubulin end, and new polymerization reactions would become relevant. Two lines of evidence show that the rate at which GDP-tubulin falls off a microtubule exceeds the off-rate for GTP binding to tubulin by two-to-three orders of magnitude, leading to the rapid disassembly of any microtubule with an exposed GDP-tubulin end.

Mitchison and Kirschner postulate that the balance between GTP-tubulin caps and GDP-tubulin ends accounts for the microtubule length redistributions they have observed. At low tubulin concentrations, the GTP-tubulin cap is short enough that statistical variation gives rise to some microtubules with an exposed GDP-tubulin end. The rapid off-rate of this state will lead to a catastrophic disassembly of those microtubules, while the polymers that retain their GTP-tubulin cap will continue to elongate. For centrosome-initiated assembly, the disappearance of a microtubule exposes a site for future polymer initiation, so the array can maintain a steady-state polymer number. In contrast, the catastrophic disappearance of a microtubule that is free in solution removes a pair of ends from the reaction mixture, so the number of polymers continually decreases as the length of those remaining increases.

The model laid out by Mitchison and Kirschner has interesting implications for the behaviour of microtubules *in vivo*, particularly for the fibres of the mitotic spindle. Their work suggests that the lability of the spindle is due to a rapid disassembly of some microtubules, the slow growth of others, and a continual reinitiation of new microtubules from the centrosomes. The length distribution of the microtubles would then be based on the acturial statistics of the GTP-tubulin caps.

While it has been known since the work of Inoue in the 1950s that spindles are labile *in vivo*, the extent of spindle dynamism has recently been shown to surpass expectations[12] and even to defy explanation by conventional wisdom about microtubule dynamics. Papers in the December issue of the *Journal of Cell Biology* by E. Salmon *et al.* and W. Saxton *et al.* will describe both the rates of incorporation of fluorescent tubulin microinjected into living mitotic cells, and the rates of fluorescence redistribution after photobleaching of fluorescent tubulin that is already equilibrated with cellular pools. The half-time for spindle microtubule turnover seems to be 10 – 20 seconds, a rate too fast to be explained by an end-exchange of subunits as conceived by Oosawa and Kasai. While the real explanation of these fast rates is not yet known, the work by Mitchison and Kirschner offers a testable model.

Their model for microtubule behaviour fits with one current concept of spindle formation — that some of the microtubules initiated at the poles are captured by kinetochores and thereby selectively stabilized. It also fits the observation that spindle microtubules, which interact with one another at the spindle midplane where fibres from the two poles interdigitate, are stabilized and can even elongate, while shorter microtubules, which fail to reach the zone of interdigitation, disassemble[13].

Mitchison and Kirschner seem to have hit on something fundamental about microtubule behaviour. It will be interesting to follow the direct test of their suggestion that the hydrolysis of the GTP-tubulin cap is responsible for the behaviour they see. Because the polymerization rate constants of actin show a similar dependence on the hydrolysis of bound nucleotide[14], it will be interesting for students of actin microfilaments to ask how much of all this thinking is also relevant to the *in vivo* behaviour of their polymer. □

1. Mitchison, T. & Kirschner, M. *Nature* **312**, 232 (1984).
2. Mitchison, T. & Kirschner, M. *Nature* **312**, 237 (1984).
3. Brinkley, B. *et al. J. Cell Biol.* **90**, 54 (1981).
4. Roobal, A. *et al. J. Cell Sci.* **55**, 365 (1982).
5. Kuriyama, R. *J. Cell Sci.* **66**, 277 (1984).
6. Oosawa, F. & Kasai, M. *J. mol. Biol.* **4**, 10 (1962).
7. Margolis, R. & Wilson L. *Cell* **13**, 1 (1978).
8. Carlier, M.-F. & Pantaloni, D. *Biochemistry* **20**, 1918 (1981).
9. Hill, T.L. & Carlier M.-F. *Proc. natn. Acad. Sci. U.S.A.* **80**, 7234 (1983).
10. Carlier, M.-F., Hill, T.L. & Chen, Y.-D. *Proc. natn. Acad. Sci. U.S.A.* **81**, 771 (1984).
11. Hill, T. & Chen, Y.-D. *Proc. natan. Acad. Sci. U.S.A.* **81**, 5772 (1984).
12. Salmon, E. *et al. J. Cell Biol.* **99**, 1067 (1984).
13. McDonald, K. *et al. J. Cell. Biol.* **83**, 443 (1979).
14. Pollard, T. *J. Cell Biol.* **99**, 769 (1984).

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Conservation

Pandering to Western pandas

from Brian Bertram

THE captive giant panda population in the West is in dire straits, consisting of only 14 animals. Apart from one baby, a mere four of them are females; they are past middle age, and only two of them are reproducing. On the other hand, there are four good unpaired males. Nonetheless there has been a dramatic improvement in the captive breeding of giant pandas in the West recently, with seven babies born over the last five years. A symposium at West Berlin Zoo on 29-30 September 1984 brought together scientists and managers from all European and North American countries

that hold the species, to share their experience and co-ordinate future action.

It became clear that the large amount of research into giant panda reproduction, perforce in captivity, has been highly productive. Recognition of peak oestrus, by both behavioural and hormonal signs, is becoming more accurate. Pregnancy can now be more reliably assessed, although not until after what seems to be about three months delay in implantation, and birth dates better predicted. The very strong maternal behaviour is becoming better understood, so techniques for artificial assistance have developed rapidly. Semen collection is almost routine and long-term semen storage is becoming more practicable. Artificial insemination techniques have benefitted from modern equipment and from recent experience of the detailed anatomy of the female giant panda.

In captivity, the species appears to be particularly vulnerable to intestinal and renal disorders. Dramatic major illnesses have developed rapidly in different collections; about half the cases have been remedied but only through rapid expert and collaborative attention.

The extent of co-operation between the keepers of captive giant pandas has been unprecedented. Within the past four years, there have been six international transfers, involving semen for artificial insemination, blood for emergency transfusions, and a live animal for mating. Veterinary staff and advice have flowed freely between institutions. Semen banks and tissue stores are being established and cell lines set up. The international studbook for the giant panda, one of many organized under the auspices of the International Union of Directors of Zoological Gardens, collects and collates information on giant panda matters. Considering the critical position of wild giant pandas, the establishment of a viable captive population is imperative. □

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