Supporting Online Information: Geometrical constraints on kinesin attachment to the microtubule

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We present here a very simplistic and rough estimate of the number of protofilaments accessible to the kinesin motors attached to the lipids of a membrane tube, and argue that these cannot use more than 3 contiguous protofilaments to pull the tube, from geometrical constraints. In Fig. 1 we sketch a cross-section of a tube and a microtubule. In order for a motor to attach to a given position on the microtubule, it must be stretched to reach that position only by thermal fluctuations. Assuming the motor to behave as a linear spring with rigidity κ, its average stretch, δz, due to thermal fluctuations reads

$$\delta z = \sqrt{\frac{2K_B T}{\kappa}} \,. \tag{1}$$

Using the measured rigidity of kinesin-1 motors, $\kappa \simeq 0.5$ pN/nm [1], we find that the motor may be stretched approximately 4 nm by thermal fluctuations. Therefore, any position on the microtubule located further away from the motor than this average stretch, is nearly out of reach for the motor.

We now estimate the average length that a motor should be stretched to reach a given protofilament (Fig. 1). We label the protofilaments with the variable n, starting from the protofilament located just below the tube ($n = 0$). If the radius of the tube is much larger than the radius of the microtubule, r_{MT}, the length, s, that a motor should be stretched to attach to the n-th protofilament reads

$$s(n) = r_{MT} \left[1 - \cos\left(\frac{2\pi n}{13} \right) \right] \,, \tag{2}$$

where we have assumed that the microtubule is composed of 13 protofilaments. Note that if the radius of the tube is comparable to that of the microtubule, this estimate corresponds to a lower bound to the real distance that the motor should be stretched. In order to reach the protofilaments just contiguous to the protofilament labeled 0, the distance δz that the motor should be stretched is, from Eq. 2, $s(n = 1) \simeq 1.4$ nm ($r_{MT} \simeq 12.5$ nm). Therefore, thermal

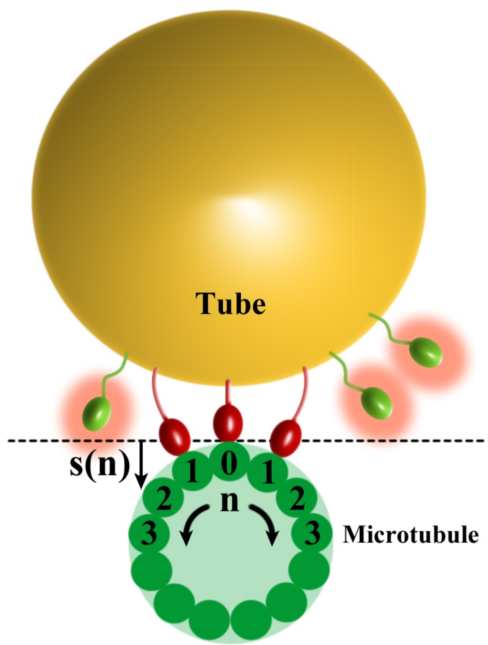

Figure 1: **Sketch of a cross section of a membrane tube and a microtubule.** The microtubule (green) is divided in 13 protofilaments (dark green), with n being the protofilament number measured from the protofilament closest to the tube ($n = 0$). The stretch of unbound motors (green; those attached to the tube but not to the microtubule) fluctuates due to thermal fluctuations. The reddish region below each unbound motor represents the region in which the motor head is fluctuating. The sketch is done using approximately the right proportions.

fluctuations can easily stretch a motor to those positions. However, in order to reach protofilaments located further away, the motor should be stretched by, at least, $s(n = 2) \simeq 5.4$ nm, which is more than what thermal fluctuations can do on average. Note that for typical values of the bending rigidity and tube force, the tube radius is about twice that of the microtubule, meaning that the last estimate is really a lower bound. Thus, it is highly unlikely that motors attached to the tube can reach protofilaments located further away than the 3 contiguous protofilaments just below the tube.

It is important to note that the kinesin motor used in our experiments has been truncated, meaning that its tail is considerably shorter than that of kinesin-1. It is expected that truncated kinesins are characterized by a larger rigidity κ. In this case, it would even be more difficult that these motors are able to attach to more than 3 protofilaments, as the motor stretching due to thermal fluctuations would be smaller.

References

[1] Kawaguchi K, Uemura S, Ishiwata S (2003) *Biophys J.* 84:1103-1113.