Supporting Material for "Stress Generation by Myosin Minifilaments in Actin Bundles"

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1. Additivity of stress contributions from different minifilaments

To evaluate the extent to which mini-filaments act independently in generating stress, we first calculated the stresses in thin bundles, with a single-minifilament in various locations. The sum of these stresses was then compared to the stress resulting from five mini-filaments acting on the same bundle simultaneously. Figure 1 summarizes the runs for 100 collections of five myosins in a bundle. The ratio of the stresses plotted here would be 1 for perfect additivity. The mean value is 0.90, indicating that the behavior is close to additive but somewhat subadditive. Similar results hold for thick bundles.

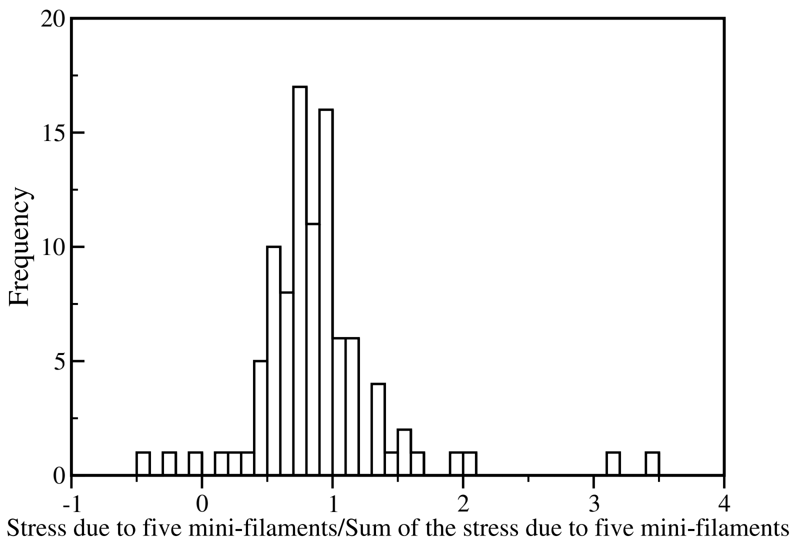

Figure 1. Ratio between stress generated in thin bundles by five mini-filaments to sum of stresses generated by the five mini-filaments acting individually. Data shown for 100 different runs.

2. Derivation of Eqs. (10) and (11) of the main text

We calculate the z-direction (up/down) force balance on the upper crosslink in Fig. 6a of the main text. This has contributions from the bending energy at the crosslink, the stretching energy of the actin filaments, and the minifilament tension. The bending energy is $E_{bend} = \kappa(2\alpha)^2/2l$. Assuming small deformations we take α to be small, so that $\sin\alpha \approx \alpha = \Delta z/l_0$, and

$$E_{bend} \simeq 2\kappa \left[\frac{(\Delta z)^2}{l_0^3}\right]. \qquad (1)$$

Thus the z-direction force on the crosslink due to bending is

$$F_{bend} = \frac{\partial E_{bend}}{\partial(\Delta z)} = \frac{4\kappa\Delta z}{l_0^3}. \tag{2}$$

(The derivative appears with a plus sign since Δz changes oppositely from the crosslink position.) The z-direction force due to stretching of the actin filament is

$$F_{stretch} = 2T_{act}\alpha, \tag{3}$$

where T_{act} is the tension in the actin filament. To obtain T_{act} in terms of Δz, we note that since $E_{stretch} = \mu(l-l_0)^2/l_0$, $T_{act} = \partial E_{stretch}/\partial l = 2\mu(l/l_0-1)$. Furthermore, simple trigonometry shows that $(l/l_0 - 1) \simeq \alpha^2/2$. Thus $2T_{act}\sin\alpha \simeq 2\mu\alpha^3 \simeq 2\mu(\Delta z/l_0)^3$, so that the force belance equation becomes

$$\frac{2\mu(\Delta z)^3}{l_0^3} + \frac{4\kappa\Delta z}{l_0^3} - T_m = 0 \tag{4}$$

Solution of Eq. (4) for Δz can be used to obtain F_{wall}, according to

$$F_{wall} = 2T_{act}\cos\alpha \approx 2T_{act} \approx \frac{2\mu(\Delta z)^2}{l_0^2}, \tag{5}$$

We solved Eq. (4) numerically to obtain the inset in Fig. 7a of the main text. The equation also has simple solutions in the limits of large and small T_m. When T_m is small, so that the Δz term in Eq. (4) exceeds the Δz^3 term, $\Delta z \approx l_0^3 T_m/4\kappa$. Then

$$\frac{F_{wall}}{T_m} = \frac{\mu l_0^4}{8\kappa^2}T_m. \tag{6}$$

When T_m is large, the Δz^3 term dominates, so $\Delta z/l_0 \approx (T_m/2\mu)^{1/3}$ and

$$\frac{F_{wall}}{T_m} = \frac{(2\mu)^{1/3}}{T_m^{1/3}}. \tag{7}$$

3. Information about videos

Movie S1:

Illustration of minifilament rotation mechanism from nearly vertical orientation on antiparallel actin filaments, for model system containing small number of filaments.

Movie S2:

Second mini-filament from left undergoes rotation from initial nearly vertical orientation on antiparallel actin filaments until it becomes parallel to the filaments and exerts a contractile force on the network. Note that the video is is truncated when this mini-filament comes to equilibrium.

Movie S3:

Illustration of minifilament rotation mechanism from initial angle close to π on two antiparallel actin filaments, for model system containing small number of filaments.

Movie S4:

a) Mini-filament furthest left in the bundle undergoes rotation from an initial angle close to π on two antiparallel actin filaments, with initial extensile stress. Its rotation decreases the angle, at first separating the filaments. As the angle decreases further, the filaments again come closer, and finally the mini-filament reaches a contractile configuration.

b) Third mini-filament from left undergoes rotation after its lower head reaches the end of the actin filament and stops there. The other head rotates around the anchoring head, and continues to move toward the barbed end, resulting in a contractile configuration.

Movie S5:

Illustration of minifilament rotation mechanism at filament tips, for model system containing small number of filaments.