Electronic Supplementary Material (ESI) for Soft Matter.

Electronic Supplementary Information

Fluctuations of a membrane nanotube revealed by high-resolution force measurements

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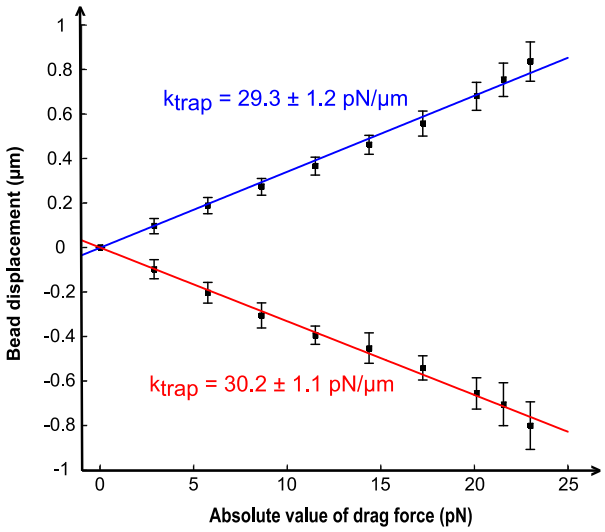

Figure S1: Trap linearity. Evolution of the bead displacement measured using the QPD as a function of the viscous force applied. Laser power is 80 mW, and the distance from the glass surface is 100 µm. The measurement is performed in two directions: negative speeds (red) and positive speeds (blue). The slopes of those fits is linked to the trap stiffness (indicated on the figure) via the relation $F_{Stokes} = k_{trap}\, d$. Those values are in correct agreement with the trap stiffness calculated through the PSD ($k_{trap} = 30.6 \pm 1.0$ pN. µm^{-1}). Error bars represent 2 SD.

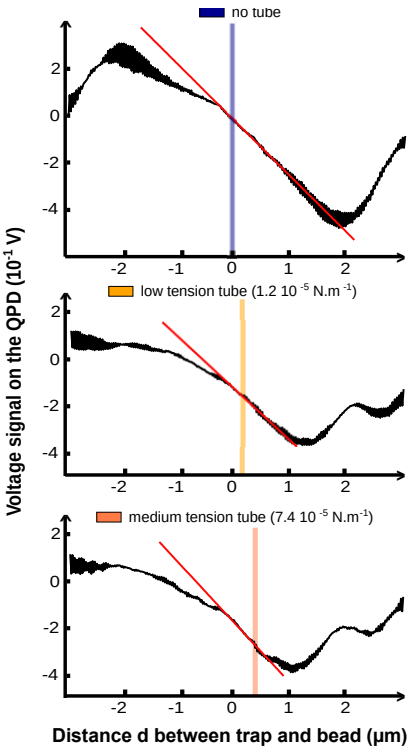

Figure S2: Positions of the bead during a tube pulling experiment in the linear regime. The bead positions change during the tube pulling experiment but the bead always remains in the linear part (red line) of the QPD calibration curve (black). "no tube" refers to a free bead (a trapped bead not attached to a tube). Slope values are (-0.24 ± 0.01) V. µm^{-1} for the bead not attached to a tube, (-0.21 ± 0.01) V. µm^{-1} for the bead attached with the low tension tube, and (-0.23 ± 0.01)V. µm^{-1} for the medium tension tube. $k_{trap} = 37 \pm 2$ pN. µm^{-1}.

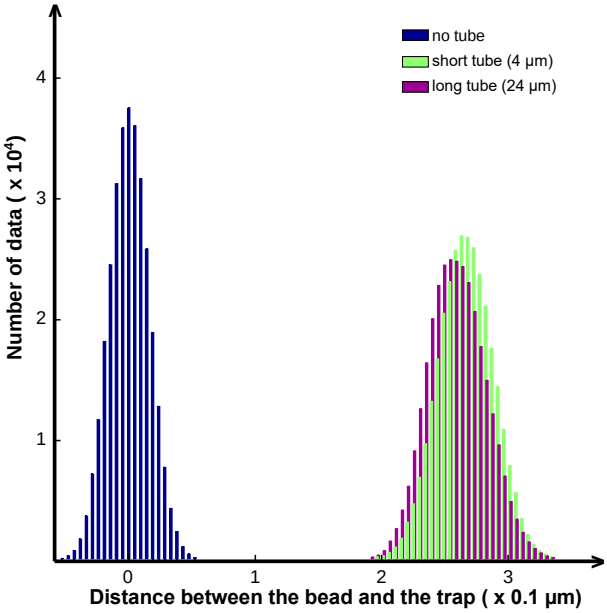

Figure S3: Distributions of the position of the bead recorded by the QPD in 5 seconds for different lengths of the same tube. Slopes are measured at $(-0.28 \pm 0.01)\,\mathrm{V.\mu m^{-1}}$ for the bead not attached to a tube, $(-0.29 \pm 0.01)\,\mathrm{V.\mu m^{-1}}$ for the bead attached with the short tube, and $(-0.26 \pm 0.01)\mathrm{V.\mu m^{-1}}$ for the long tube. $k_{trap} = 35 \pm 2\ \mathrm{pN.\mu m^{-1}}$.

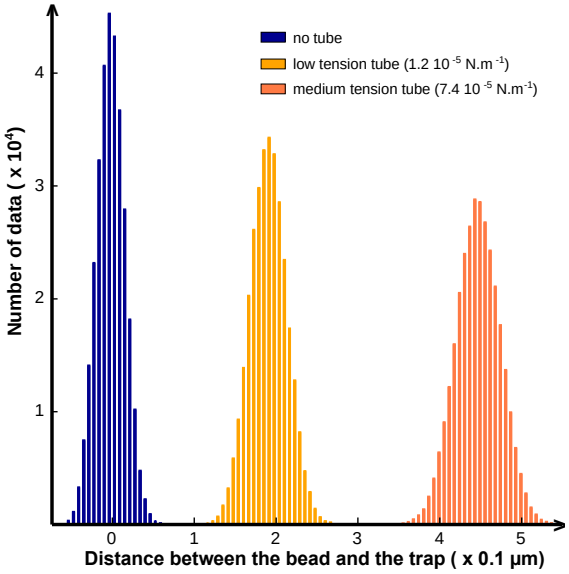

Figure S4: Distributions of the position of the bead recorded by the QPD in 5 seconds for different tensions of the same tube. Slopes are measured at $(-0.24 \pm 0.01)\,\mathrm{V.\mu m^{-1}}$ for the bead not attached to a tube, $(-0.21 \pm 0.01)\,\mathrm{V.\mu m^{-1}}$ for the bead attached with the low tension tube, and $(-0.23 \pm 0.01)\mathrm{V.\mu m^{-1}}$ for the medium tension tube. $k_{trap} = 37 \pm 2\ \mathrm{pN.\mu m^{-1}}$.

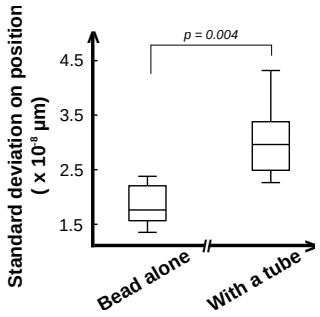

Figure S5: Standard deviation of the position of the bead before and after a tube is pulled (obtained on $N = 9$ independent experiments).

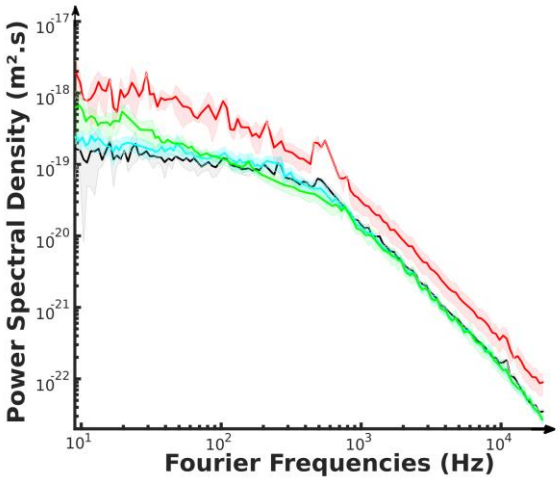

Figure S6: Comparison of PSDs of free beads (blue and black), beads bound to the membrane without a tube (green), and beads maintaining a tube (red). Mean of PSD for 6 free beads (blue) and then bound to liposomes (green). Membrane tension is $\sigma = (3.6 \pm 0.9)\ 10^{-5}\ \mathrm{N.m^{-1}}$ and trap stiffness $k_{trap} = (37 \pm 2)\ \mathrm{pN.\mu m^{-1}}$. Slope values are $(-0.39 \pm 0.02\ \mathrm{V.\mu m^{-1}}$ for the free beads and $(-0.38 \pm 0.02)\ \mathrm{V.\mu m^{-1}}$. Black and red curves are reproduced from Fig. 3(a).

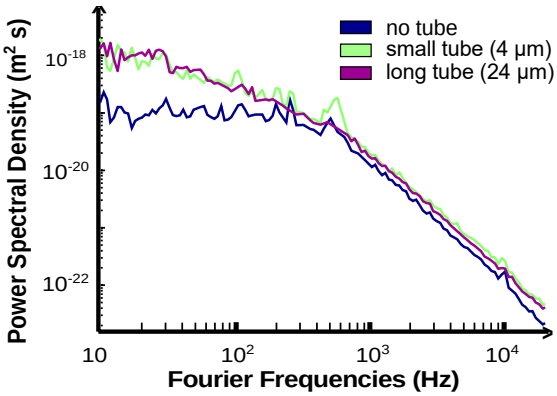

Figure S7: Effect of tube length on the PSD. PSD of a free bead (blue) compared to the PSDs of the same bead attached to tube at different length. Slopes are measured at $(-0.28 \pm 0.01)\ \mathrm{V.\mu m^{-1}}$ for the bead not attached to a tube, and $(-0.26 \pm 0.01)\ \mathrm{V.\mu m^{-1}}$ for the long tube. $k_{trap} = 35 \pm 2\ \mathrm{pN.\mu m^{-1}}$.

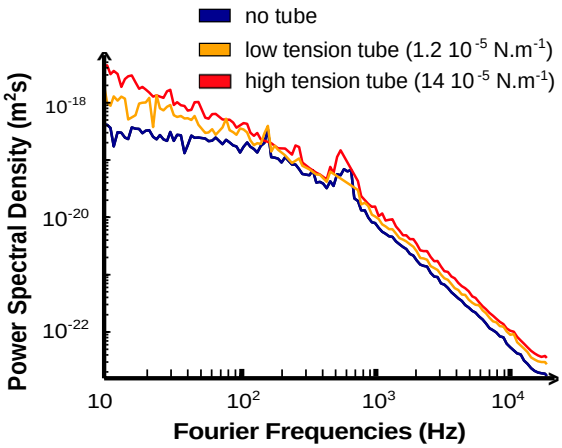

Figure S8: Effect of tube tension on the PSD. PSD of a free bead (blue) compared to the PSDs of the same bead attached to tube at different tension. Slopes are measured at $(-0.28 \pm 0.01)\,\mathrm{V.\mu m^{-1}}$ for the bead not attached to a tube, $(-0.26 \pm 0.01)\,\mathrm{V.\mu m^{-1}}$ for the bead attached with the low tension tube, and $(-0.30 \pm 0.01)\,\mathrm{V.\mu m^{-1}}$ for the medium tension tube. $k_{trap} = 43 \pm 2\ \mathrm{pN.\mu m^{-1}}$.

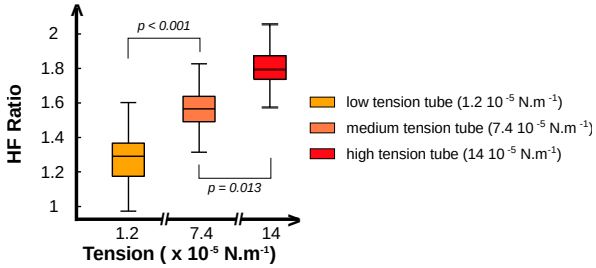

Figure S9: Effect of the tension on the exponent at high frequency. Estimation of the ratio PSD with tube / PSD without tube measured between 1 kHz and 10 kHz ($n = 2$).

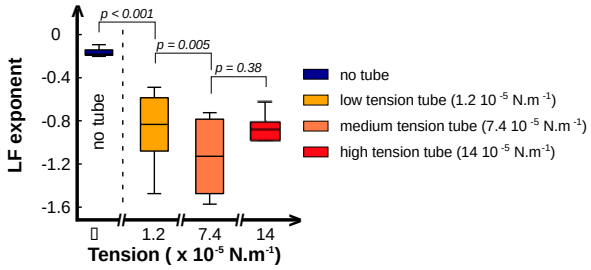

Figure S10: Effect of the tension on the ratio $\mathrm{PSD_{tube}}$ / $\mathrm{PSD_{freebead}}$ at low frequency. Estimation of the slope of PSDs measured between 10 and 200 Hz (in log log plot) in function of the liposome tension of the pulled tube ($n = 2$).