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Corrigendum

Corrigendum to "Large deformation of living cells using laser traps" [Acta Materialia 52 (2004) 1837–1845] ☆,☆☆,★

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This recently published paper reported large deformation tensile stretching of human red blood cells using laser traps. Unfortunately, the published version of the manuscript contained some errors which could not be corrected prior to publication. In this corrigendum, we report these corrections by presenting revised figures wherever appropriate and point to some modified inferences and conclusions. These modifications are also based on new experimental data and calibration methods which will be reported in detail in a forthcoming publication [1].

The second sentence of the abstract should read: "The maximum external force imposed on the cell is estimated to be on the order of 193 ± 20 pN". This maximum force limit is also applicable throughout the discussion in the paper and in the first conclusion on page 1844. The first sentence of the last paragraph of the Introduction section should read: "Here, we demonstrate use of optical tweezers to study the deformation characteristics of the human red blood cell with stretching forces that appear to be three to six times larger than those imposed previously with optical tweezers on the human red blood cell".

The second sentence which follows equation (2) should be corrected as follows: "Using a Rheometric fluid spectrometer (Rheometrics Scientific, Piscataway, NJ), the viscosity of the PBS solution was measured to be $\eta_f = 0.0013$ Pa s". On the basis of corrections made to the original data that appeared in the paper and from new experimental data obtained subsequent to the submission of the original paper, the new corrected Fig. 3 showing the force calibration curve is given below. The filled data points show forces greater than 20 pN where a linear variation between laser power and trapping force was consistently found. The standard deviation in the force values was less than 15% up to 70 pN stretching force. If the plot of the escape force versus incident laser power is extrapolated linearly to maximum laser power, a maximum estimated force of 193 pN with a likely maximum error of ± 20 pN was found based on repeat calibrations results. The laser power is measured just before the beam enters the objective lens. The linear relationship between laser power and escape force is also suggested by theoretical predictions [2] and empirical findings [3].

A stage-movement escape force method [1,2] for force calibration was used to modify the original data. Although a flow chamber method was used in the original study, the escape force method provided a more reliable and repeatable force calibration for our optical tweezer set-up [3].

The corrected new Fig. 7 showing images of deformation along with simulated deformation and strain evolution based on the computational model described in Section 3.2 is given here. Fig. 7 shows that observed shape changes are reasonably matched by computation for which μ_0 was assumed to be 5.5 μN/m (with $\mu_l = 3.3$ μN/m). Video clips of three-dimensional computational simulations can be viewed in the supplementary material attached to this corrigendum.

The new Fig. 8 shown here, which replaces the original Figs. 6 and 8 in one combined plot, compares the

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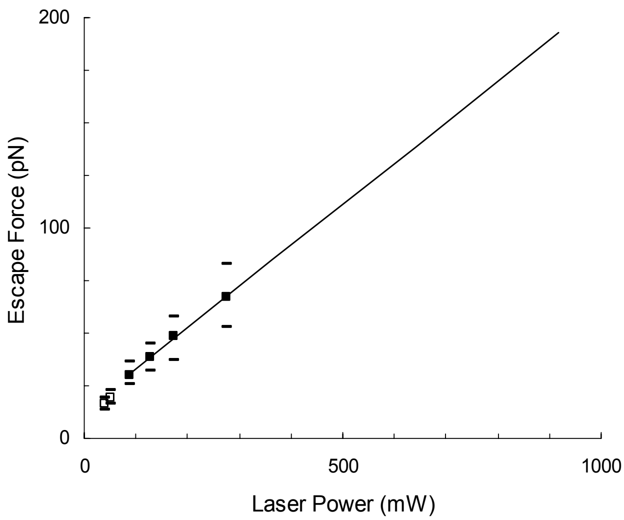

Fig. 3. Updated force calibration curve. The filled data points show forces greater than 20 pN where a linear variation between laser power and escape force was consistently found.

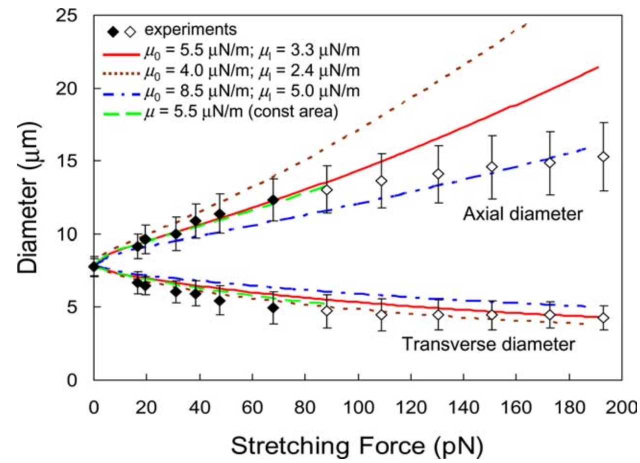

Fig. 8. This figure replaces the original Figs. 6 and 8 in one combined plot, and compares the corrected predictions of the computational model presented in the paper with experimental observations. The filled symbols show experimental data for which direct calibration was obtained and the open symbols indicate data for which the force was extrapolated linearly with laser power as shown in Fig. 3.

corrected predictions of the computational model presented in the paper with experimental observations. Fig. 8 also reveals that simulations using the model depicted in Fig. 5 of the paper with μ_0 values in the range of 4.0–8.5 μN/m and μ_l values of 2.4–5 μN/m capture the diameter changes in the axial and transverse directions over the range of imposed forces from 0 to 85 pN. Alternatively, if one employs the constant area assumption and the model given by Eqs. (3a)–(3c) of the paper, a shear modulus value of 5.5 μN/m captures the experimental trends up to a force of about 85 pN. It is found that these estimates of shear modulus values shown in Fig. 8 are fully consistent with the estimates of 3–9 μN/m made previously using micropipette aspiration experiments (see, for example [6] in the original paper). Computational results using an improved model which better match the experimental curves beyond 85 pN stretching force will be reported later [1].

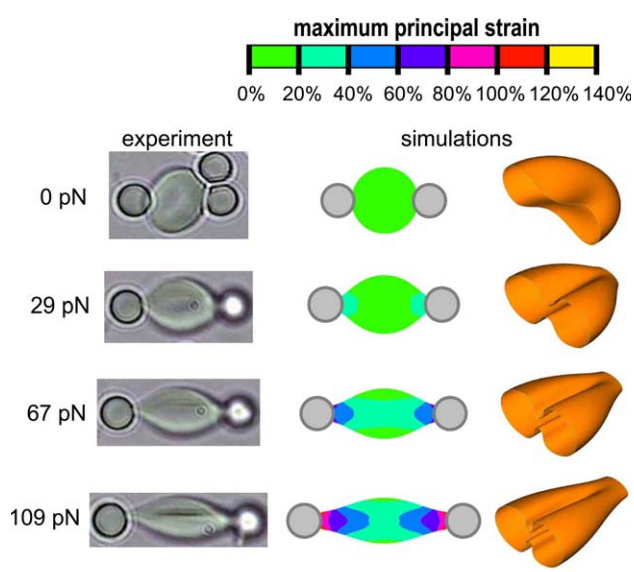

Fig. 7. Images of the red cell stretched from 0 to 109 pN. The images in the left column are obtained from experimental video photography whereas the images in the center column (top view) and in the right column (half model 3D view) correspond to large deformation computational simulation of the biconcave red cell (with $\mu_0 = 5.5$ μN/m, $\mu_l = 3.3$ μN/m). The middle column shows a plan view of the stretched biconcave cell undergoing large deformation at the forces indicated on the left. The predicted shape changes are in reasonable agreement with observations. The color contours in the middle column represent spatial variation of constant maximum principal strain. The right column shows one half of the full three-dimensional shape of the cell at different imposed forces; here, the membrane was assumed to contain a fluid, which preserved the internal volume.

The viscoelastic relaxation response reported in Fig. 9 of the paper remains unaffected by the corrections presented here.

Further details on improved calibration methods for large deformation stretching of human red blood cells by laser traps and on improvements to the models will be described in a forthcoming paper by Mills et al. [1].

We thank J. P. Mills and L. Qie for their help in preparing this corrigendum.

Video clips of three-dimensional computational simulations of the biconcave cell membranes based on the corrected data shown here can be viewed at the supplementary material available along with the electronic archive of this corrigendum.

References

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