Strain and Strain Recovery of Human Hair from the Nano- to the Macroscale

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Motivation

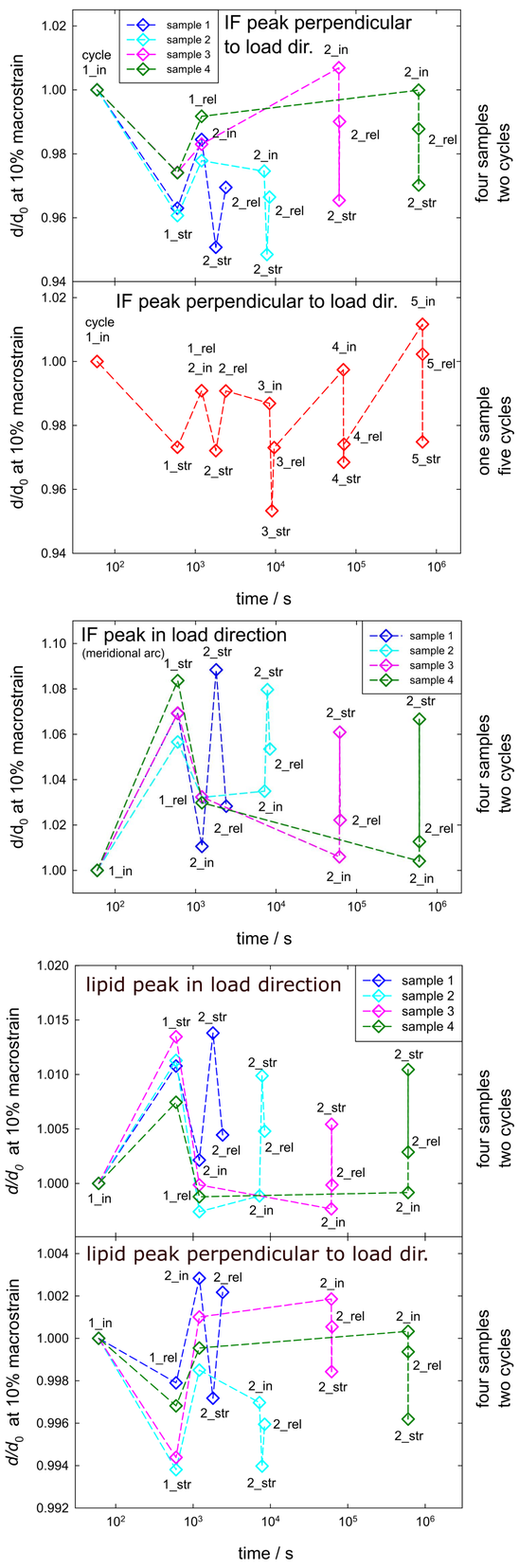
Hair, like many other biological composites, is a multi-level hierarchical material. It has several structures in between the nano- and the macrolevel. In this study, our goal was to gain a quantitative insight into structural mechanics and relaxation behavior of this composite material, by straining hair during in operandi SAXS measurements in a laboratory setup. A special focus was placed on comparing the nano- to the macrostrain in order to understand the relaxation behavior of hair at different structural levels.

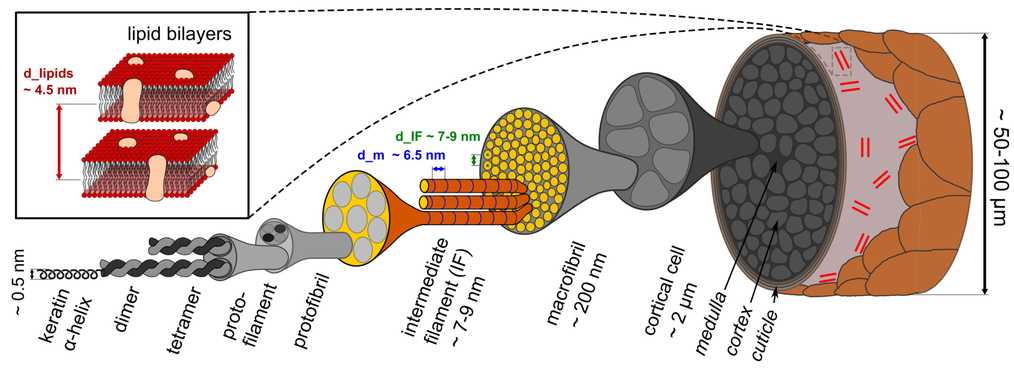
Method

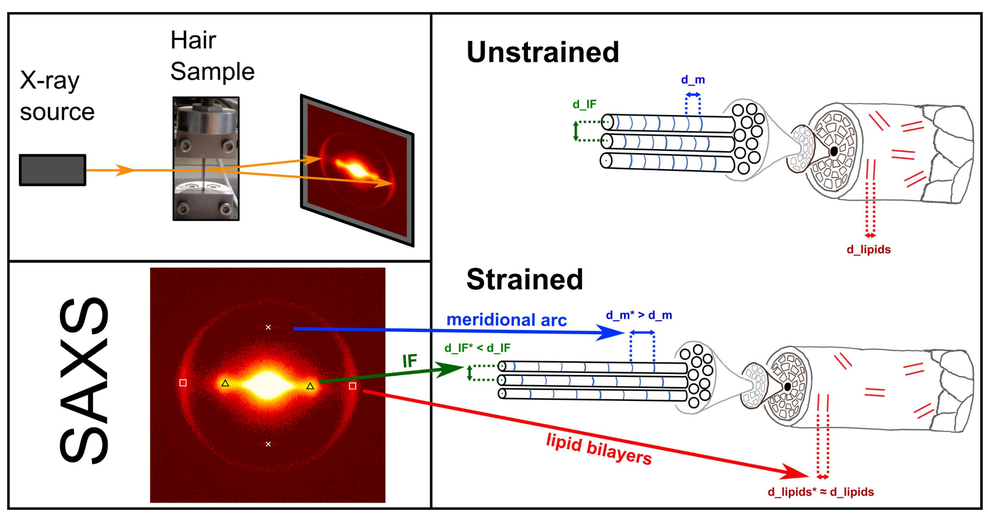
- SAXS: Cu-Kα ($\lambda = 0.1542$ nm) was used for in operandi experiments.
  - A tensile test machine was used inside the SAXS chamber.
  - Samples were subjected to 2% and 10% strain, within and beyond the elastic regime, respectively.
  - Re-straining after a waiting period of 10^1, 10^2, 10^3, and 10^4 min.
  - SAXS images were taken before, during, and after each straining.
- SEM: micrographs of strained and unstrained hair were taken.

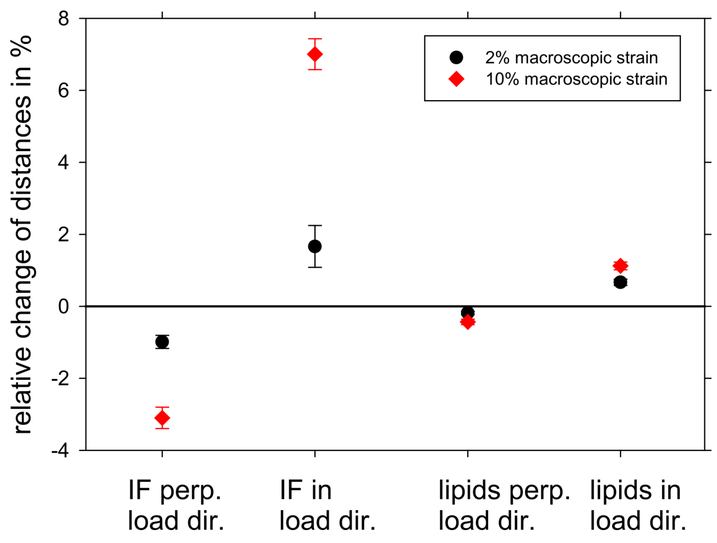
Results

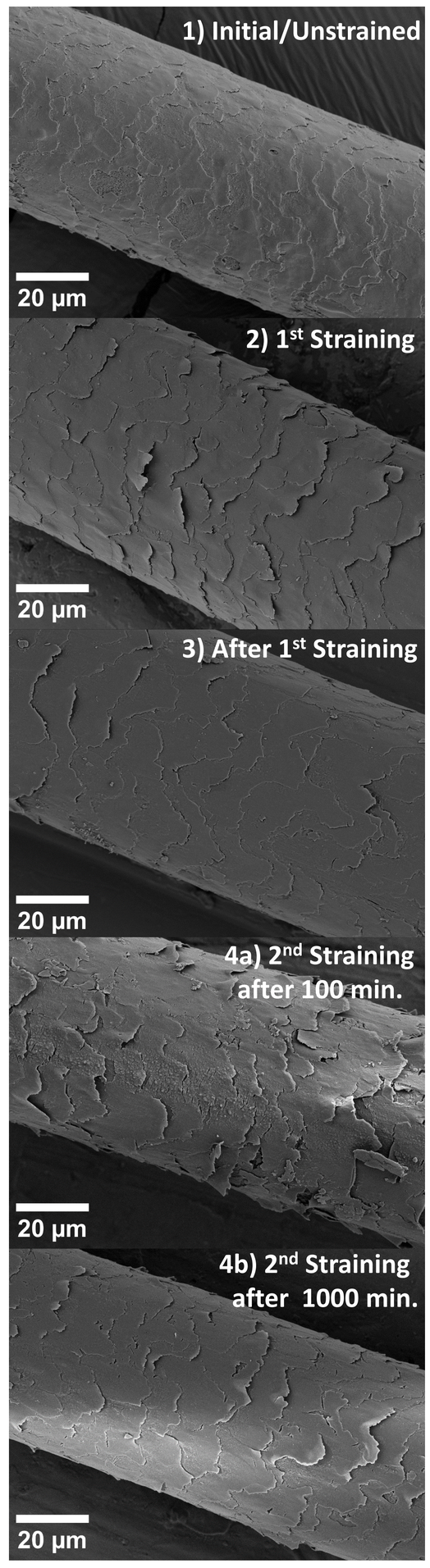
Effect of macrostrain cycles and different waiting periods on the nanostrain d/d_0, evaluated in and perpendicular to load direction.
Abbr.: *_in*: initial, *_str*: strained, *_rel*: relaxed











Conclusion

- High deformation of intermediate filaments (IF) with a nanostrain d/d_0 reaching 70% of the macrostrain. The nanostrain in lipids is considerably smaller by a factor of 6.
- Nanoscale Poisson ratio in hair:
  intermediate filaments: $\nu_{\mathrm{nano}} = 0.44$,
  lipid bilayers: $\nu_{\mathrm{nano}} = 0.40$.
- The relaxation time of hair is between 100 and 1000 minutes.
- No additional effect of repeated straining.

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