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Balance of forces and torques in a mean-field approximation in mitotic spindles

The mitotic spindle is a self-organized micro-machine composed of microtubules and associated proteins, which divides genetic material between its two nascent daughter cells. Forces exist in the spindle throughout mitosis and are crucial for spindle functioning in each phase. In metaphase, the mitotic spindle has a recognizable shape with a characteristic arrangement of microtubules. Microtubules extend from opposite spindle poles and interact with the chromosomes and with each other. Though a significant progress in understanding the mechanics of the spindle has been achieved, the question of force balance in the spindle is still open. We aim to explore the force balance of the entire spindle, based on our previous work on individual microtubule bundles. We describe the force balance of the spindle by introducing a mean-field approach, in which discrete microtubule bundles in a certain region, together with forces and torques exerted by these bundles, are approximated by an averaged bundle. The model provides predictions for forces and torques in the spindle, and consequently it predicts the shape of the entire spindle, including the shapes of inner and outer bundles. The predicted shapes will be compared with shapes observed in our experiments. Based on this information, we provide a mechanical explanation for the shapes of inner and outer bundles, including major differences between them. This approach provides comprehensive insight into forces and torques acting in the entire spindle, which are crucial for proper cell division.

Primary author(s) : IVEC, Arian (Faculty of Science, University of Zagreb); Prof. PAVIN, Nenad (Faculty of science, University of Zagreb); TOLIĆ, Iva (Ruđer Bošković Institute, Zagreb, Croatia)

Presenter(s) : IVEC, Arian (Faculty of Science, University of Zagreb)

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