Active Smectics in Developing Tissues

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Active liquid crystals provide physical models for biological systems [1], such as the cytoskeleton, epithelial monolayers and biofilms. They have been successful in capturing orientational order and spontaneous motion in cell populations, connecting structural order to mechanical stress and in highlighting the significance of topological defects in cell apoptosis and in morphogenesis. However, so far the applications of the theory have been primarily two-dimensional (2D) and for nematic, or polar, order and there is considerable unrealised potential for other phases of active liquid crystals. In three dimensions, liquid crystals display a greater diversity of textures and additional modes of deformation, namely twist and saddle-splay. Likewise, the packing and shapes of cells within 3D tissues displays enhanced geometric diversity; elongated cells can be twisted as well as stretched and exhibit distinct neighbour rearrangements. One reason that progress has been limited in this field is the challenge of accurately describing the 3D cell and tissue morphologies given the inherent noisiness of biological data. Recent advances in imaging and machine-driven cell segmentation now mean we can access precise 3D cell shape information [2].

As part of a collaboration with Prof. Tim Saunders (WMS), we will develop theoretical models for how cells shape in 3D within tissues, using the forming zebrafish skeletal muscle (myotome) as a model system that is accessible for live 3D imaging. The skeletal muscle has a periodic structure [3] analogous to that of a smectic liquid crystal, with each myotome serving as a smectic layer. We will develop the theory of active smectics [4, 5] to model the mechanical properties of the large scale muscle structure. Fitting to experimental data will provide quantitative measurement of activity and mechanical moduli in living tissues. Beyond the large-scale structure, we will also develop the theory for the spatial organisation of cells within the tissue and for their twisted 3D shapes. As cells pack into tissues, structural phase transitions (*e.g.,* jamming and percolation) can occur, in addition to the formation of the liquid crystalline order. Previous analysis has been largely limited to 2D: how cells shape and pack in three-dimensions within dense tissues is an open question. This project will develop a robust, quantitative framework for understanding the structure and formation of 3D tissues by utilising ideas from active matter, liquid crystals and topology.

References

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