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From nature to nanoscale: The evolving landscape of surface microfluidics in cellular research

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Nature has always offered elegant solutions to complex engineering problems. The self-cleaning lotus leaf and the drag-reducing texture of shark skin illustrate how microscopic surface structures can shape fluid behaviour with remarkable precision. These examples lie at the heart of **biomimetics**: a research field that draws inspiration from natural systems to develop innovative engineering and scientific solutions. Biomimetics continues to inspire new directions at the intersection of microfluidics, materials science, and biology, offering strategies for designing functional surfaces and devices that replicate nature's efficiency at the microscale.

Microfluidic systems, platforms that manipulate minute fluid volumes in microscale environments, have revolutionised biological research. They enable controlled studies of cells, molecules, and reactions in conditions that closely mimic nature. Building on these advances, scientists are now exploring a new frontier: **surface microfluidics**. Unlike traditional closed-channel designs, this approach harnesses engineered surfaces to guide and manipulate fluids directly through surface energy and topology.

By designing surfaces with specific roughness, wettability, or patterns, researchers can achieve precise control of liquid motion without pumps or valves. Early studies on biomimetic superhydrophobic and anisotropic surfaces revealed that small geometric modifications could significantly influence drag, spreading, and wetting dynamics. These discoveries laid the foundation for a new way of thinking about microscale fluid management, one that integrates physics, chemistry, and biology on a single platform.

In the biomedical arena, surface microfluidics promises to transform how we handle and analyse living cells. Controlled surface architectures allow scientists to explore how cells respond to physical cues such as stiffness, roughness, and curvature. These are factors that strongly influence cell growth, migration, and differentiation. Such insights are central to developing more realistic disease models, improving drug testing, and advancing personalised medicine.

Beyond cellular studies, the integration of surface engineering with digital technologies is reshaping the future of microfluidics. Artificial intelligence and automated data analysis are accelerating discovery by predicting how specific designs affect fluid behaviour and biological responses. Meanwhile, advances in precision fabrication, such as laser machining and additive manufacturing, are enabling structures of extraordinary complexity and reproducibility.

Although challenges remain in ensuring biocompatibility, durability, and scalability, the trajectory of this field is clear. Surface microfluidics represents a paradigm shift: from passive observation to active design of fluid–surface interactions. By combining inspiration from nature with cutting-edge technology, researchers are now creating systems that are smaller, smarter, and more adaptive than ever before.

Advances in Cells provides an ideal platform for this growing conversation. By promoting open access and interdisciplinary collaboration, the journal plays a pivotal role in connecting ideas from physics, biology, and engineering. These can foster innovation that will shape the next generation of cellular and microfluidic research.

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The author did all the research work for this study.

Conflict of Interest

The author declares no conflict of interest.

