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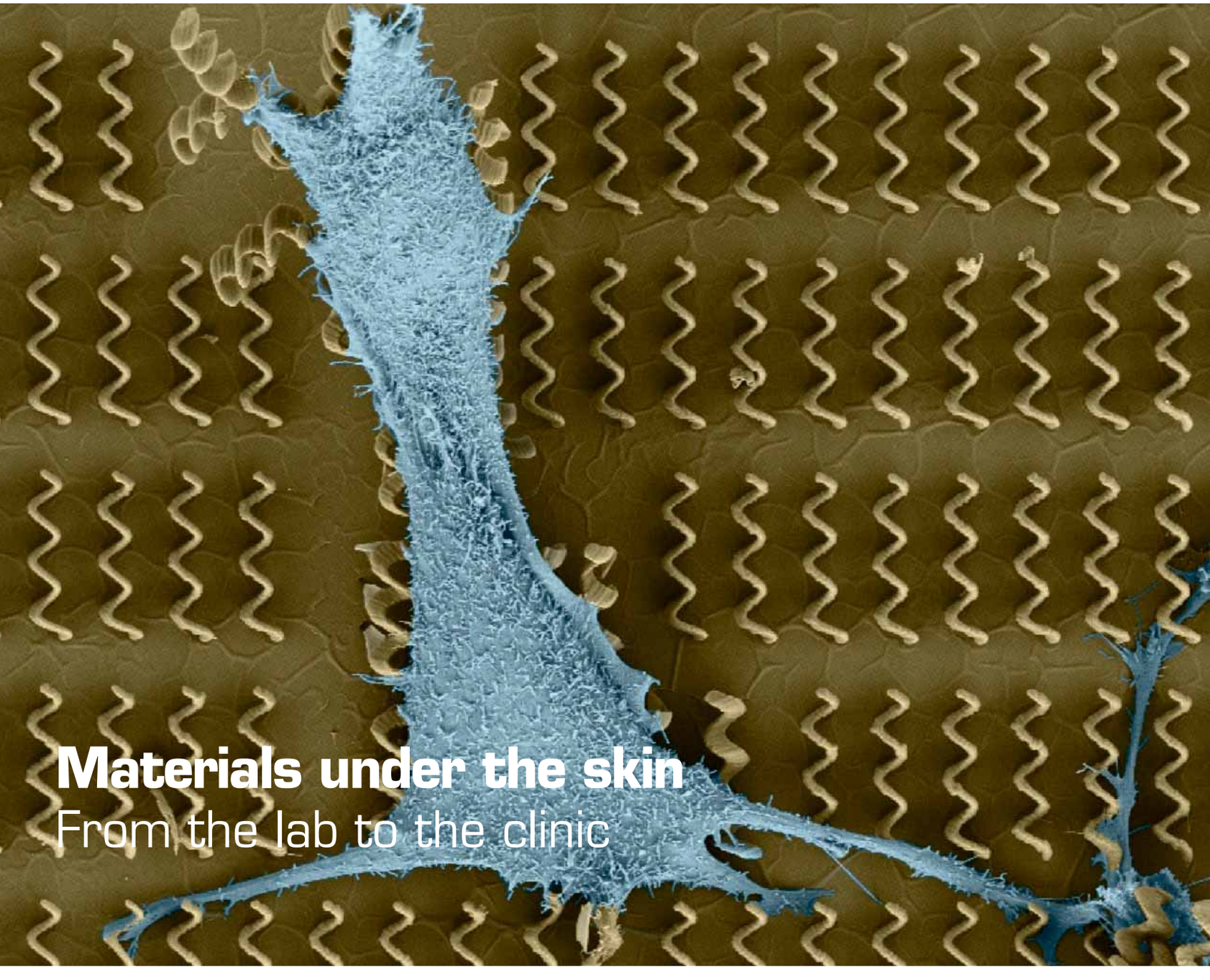


Materials under the skin

From the lab to the clinic

D. W. Hutmacher looks at bone tissue engineering

Y. Mei on microarrayed materials for stem cells

J. Burdick discusses the extracelluar matrix

Bio-inspired microrobots

The first intimate contact with cells

Famin Qiu[1], Li Zhang[1,2,*], Soichiro Tottori[1], Klaus Marquardt[3], Krzysztof Krawczyk[4], Alfredo Franco-Obregón[4] and Bradley J. Nelson[1].

[1] *Institute of Robotics and Intelligent Systems, ETH Zurich, Switzerland*

[2] *Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong, Hong Kong SAR, China*

[3] *Center of Microscope and Image Analysis, University of Zurich, Switzerland*

[4] *Space Biology Group, ETH Zurich, Switzerland*

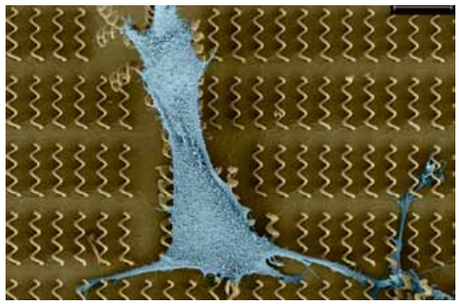
[*] *E-mail: lizhang@mae.cuhk.edu.hk*

Medical microrobots have the potential to revolutionize minimally invasive medical tasks, such as targeted therapy, material ablation, and telemetry, particularly for difficult-to-reach locations inside the human body[1]. Key technological hurdles which must be overcome include the development of methods for delivering energy to microrobots and the development of propulsive techniques. Among various approaches for powering wirelessly controlled microrobots, magnetic field actuation is promising for *in vivo* applications, because magnetic fields are harmless to living cells and biological tissue. In the development of locomotion, nature provides guidance.

In hydrodynamics it has been known for more than a half century that in a low-Reynolds number regime non-reciprocal motion is required for a self-propelling device. In the 1950s Taylor proposed that traveling waves propagating along a tail was the mechanism by which spermatozoa propel themselves[2]. In 1973, Berg discovered that some bacteria, such as *E. coli*, swim at Reynolds numbers as low as 10^{-4} by rotating their helical-shaped flagella[3]. Inspired by the design of bacterial flagella, helical swimming microrobots with comparable dimensions to their natural counterparts have been recently developed in Nelson's group at ETH Zurich[4]. The first generation of helical swimming microrobots, artificial bacterial flagella (ABFs), were fabricated using self-scrolling techniques and consist of soft-magnetic thin-square-plate "heads" and helical nanoribbon "tails"[5]. A uniform low-strength (2 mT) rotating magnetic field generated by a three-axis orthogonal Helmholtz coil system actuates the ABFs in water. The magnetic-torque-driven ABFs swim with corkscrew motion and can be navigated in 3D with all six degrees-of-freedom.

Our previous work reported that when the magnetic helical devices are scaled to the microscale, magnetic-torque-driven helical devices exhibit higher swimming performance than direct pulling using magnetic field gradients, assuming the same limitation of the electromagnetic-coil system[6]. These ABFs provided an alternative micromanipulation tool for manipulating cellular or subcellular objects with or without a physical contact[4,7]. Furthermore, since the propulsion matrix that serves as a swimming model can be estimated experimentally[8], manipulation with a controlled force or torque can be applied.

While this unique technological breakthrough has potential for *in vivo* robotic drug delivery and cell manipulation, two key issues yet to be addressed are the biocompatibility and the functionalization of the helical devices. Recently, Tottori *et al.* discovered a simple and general fabrication method to fabricate a new generation of helical microrobots of essentially arbitrary design using direct laser writing and thin film deposition[9]. The as-fabricated helical microrobots consist of a photo-curable SU-8 or IP-L polymer body coated with a Ni/Ti bilayer. Potential cytotoxic effects of the device surface treatments were tested using



mouse myoblast cells (C2C12) incubated for 72 hours. The results indicate that on substrates coated with SU-8 and a Ni/Ti bilayer, the cells grew at approximately the same rate as they did on a bare glass substrate[9]. In addition, these helical swimming microrobots exhibit excellent swimming performance. For instance, a 2 μm diameter and 8.8 μm long helical swimming microrobot attained a velocity of 127 μm/s (14.4 body lengths per second) in water with an input frequency of 175 Hz at 7.5 mT[9].

This month's cover image shows a C2C12 cell interacting with an array of helical swimming microrobots via lamellipodial and filopodial interactions. The helices, consisting of photo-curable polymer "bodies" coated with a thin Ni/Ti bilayer, were fabricated using two-photon polymerization direct laser writing and electron beam evaporation. In order to test for potential cytotoxic effects of the device surface treatments, the mouse muscle cells were lightly fixed prior to SEM inspection after 24 hours of cell incubation. The results reveal that the materials comprising the helical devices were not cytotoxic to the myoblasts as the cells readily adhered, migrated and proliferated over them. In order to inspect the interaction of cells and these helical devices by scanning electron microscopy (SEM), the cells were treated by critical point drying after a fixation process to maintain their morphology[9]. The image was taken with a ZEISS SUPRA 50VP (Carl Zeiss, Germany) SEM at an accelerating voltage of 5 kV, using the SE2 detector.

FURTHER READING

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