PhD PROJECT PROPOSAL

PhD PROJECT TITLE

Topological Design of Anti-fouling Surfaces for Biomedical Devices

PhD SUPERVISORY TEAM

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PhD PROJECT DETAILS

Project abstract

Significant incidence of hospital-acquired infections due to fouling of biomedical devices is a major threat contributing to prolonged hospital stay and death. Specifically, invasion of bacteria to human bodies via surgical instruments and catheters is made utterly easy by the presence of liquids such as urine, blood and even water/moisture. In this project, robust liquid-repellent surfaces with biofouling-resistant properties will be topologically designed to prevent contamination on biomedical devices. State-of-the-art fabrication techniques (3D

printing and laser-based machining) will be used to create distinct surface topologies. This will lead to inherent anti-fouling properties by preventing wetting and adhesion of contaminating liquids.

Applications of Topology

This project aims to utilise ultra-liquid-repellent surfaces with hierarchical micro-nanoporous structures to curtail biofouling. Here, topological design will enable the realisation of complicated surface morphology with minimum pore sizes, which determine the lower size limit of contaminants. Micro-scale surface topologies will be created as a base layer using 3D printing and laser machining. Furthermore, a top layer of porous nano-filament will be introduced as overhanging topology to minimise the fraction of solid surfaces that can be wetted by the contaminating liquids. The topological features will thus allow one to produce robust ultra-liquid-repellent surfaces without subsequent chemical treatment.

DETAILED PROJECT DESCRIPTION

The fouling of biomedical devices will put patients needlessly at risk of infection and contributing to the burden imposed by healthcare-associated infections in National Health Service (NHS). For example, indwelling urinary catheters are responsible for most hospital-acquired urinary tract infections (UTIs),[1] which account for approximately 35-40% of all hospital-acquired infections.[2, 3] This is followed by surgical site infections that account for 20% of all hospital-acquired infections.[2] The pathogenesis of these infections is related to the susceptibility of device/instrument surfaces to bacterial adhesion and microbial colonization,[4-6] especially in the presence of fouling liquids such as urine, blood and even water/moisture.

However, the healthcare-associated infections may be preventable, by using topologically designed ultra-liquid-repellent surfaces (against highly contaminating media). The aim of this project is to develop robust ultra-liquid-repellent surfaces with topological features that can be used to contain the wetting and adhesion behaviours of fouling liquids.
'Wetting' refers to the study of how a liquid deposited on a surface spreads out.[7] On a fully wettable surface, droplets of liquid will spread spontaneously to form a thin film. By contrast, droplets on an ultra-liquid-repellent surface will assume an almost spherical shape with a contact angle approaching 180°, resulting in a minimum liquid-solid contact area as well as low interfacial adhesion forces. The principal supervisor's recent work has demonstrated that the adhesion and spreading behaviours of liquid droplets depend on the surface structure and wettability (How drops start sliding over solid surfaces, Nature Physics, 2018). It has also been revealed in the principal supervisor's work with colleagues (When and how self-cleaning of superhydrophobic surfaces works, Science Advances, 2020) that the pore size of water repellent surfaces determines the lower size limit of contaminant particles. This indicates that the pore size of a porous surface is the most important factor to achieve a high contamination resistance. Further, active matters including cells and biofilms have been found to behave like liquids on long timescales, and their spreading regimes can be described in the framework of wetting (Figure 1).

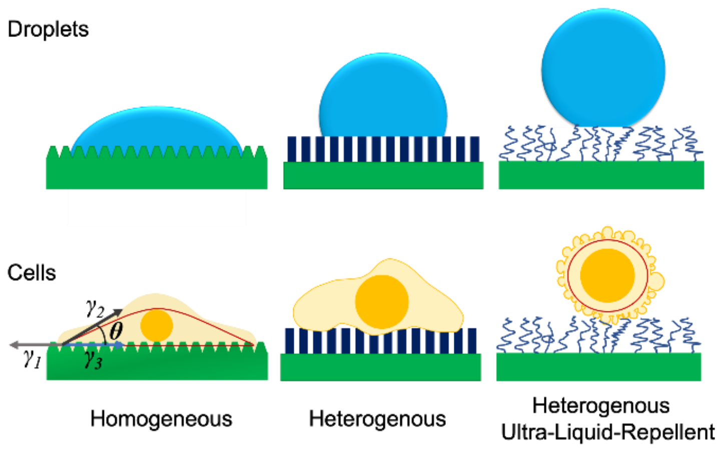

Figure 1. Schematic illustration of the analogy between droplets (upper row) and cells (lower row), in terms of wetting states, on substrates with different wettability. The shapes of a cell can be qualitatively understood by comparing with that of a liquid droplet, whereby a balance of three interfacial tensions (γ_1, γ_2 and γ_3), in addition to substrate structure & roughness, determines the equilibrium contact angle (ϑ).

As such, we will design surface topologies to manipulate the wetting behaviours as well as the anti-fouling performance in this project. In particular, the geometrical freedom of topologically structured surfaces will enable the realisation of hierarchical micro-nano-porous morphologies to minimise the pore sizes and thus the lower size limit of contaminants. 3-D printing and laser machining will be used to fabricate micro-structured surfaces on substrates including polymer, glass and stainless steel. A layer of porous nano-filament will be subsequentially coated on top of the micro-structured base layer to form an overhanging geometry. This will result in hierarchical micro-nano-structures that can prevent any fouling liquids from wetting the surfaces.

• Training and skills to be developed over the PhD

Over the course of the PhD project, the student is expected to develop knowledge and skills that will equip him or her to undertake independent research at the frontier of surface fabrication, biomedical engineering and healthcare technologies. The student is also expected to take up employment in policy or practice communities that exploit such knowledge. To enable the student to achieve this goal, the PhD programme will offer a range of opportunities in subject-specific training and research methods training.
The subject-specific training relates to the bodies of knowledge needed to master fabrication techniques such as 3-D printing, laser machining and surface coating. The research methods training will provide a theoretical and practical grounding in analytical skills including data analysis, software and data collection. This challenging project will bring the PhD candidate excellent research experience across topological design, cutting-edge material characterisation, and data analysis.

• Explanation of why the project is suitable for the CDT in Topological Design

This multi-disciplinary project will bring together biomedical engineering, advanced manufacturing and healthcare technologies to enable the topological design of ultraliquid-repellent surfaces. It will contribute to the application of topologically structured ultra-liquid-repellent surfaces onto biomedical devices. In addition, it will be related to ‘real world’ problems so that the analysis performed by the PhD student will resonate with the substantive questions he or she is exposed to in biomedical engineering and healthcare technologies and even wider areas.

- Links with research groups and research strategies

The project supervisors have established a strong interdisciplinary network with researchers (Prof Duncan Shepherd, Prof Stefan Dimov, Dr Carl Anthony, Dr Daniel Espino, and Dr Felicity de Cogan) across the College of Engineering and Physical Sciences and the College of Medicine and Dental Sciences at the UoB. The research through this PhD project will be heavily linked to the Biomedical Engineering Research Group and the Healthcare Research Group. It will also be linked to industrial applications in biomedical devices and healthcare technologies.

- An ideal/acceptable undergraduate background and interests

PhD candidates should be strongly motivated to undertake multidisciplinary research in a highly collaborative environment. The candidates should have or be about to obtain a good degree (at least 2.1) in chemical engineering, materials science and engineering, mechanical engineering, physics or a related subject, with excellent communication skills. Experience in micro-fabrication and biomedical engineering would be an advantage, but not necessary.

References:

1. Miller, B.L., et al., Infection Control & Hospital Epidemiology, 2013.
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4. Zhang, S., et al., ACS Biomaterials Science & Engineering, 2019.
5. Trautner, B.W. and R.O. Darouiche, American Journal of Infection Control, 2004.
6. Feneley, R.C.L., I.B. Hopley, and P.N.T. Wells, Journal of Medical Engineering & Technology, 2015.
7. De Gennes PG, Brochard-Wyart F, Quéré D. Capillarity and wetting phenomena: drops, bubbles, pearls, waves. Springer Science & Business Media, 2013.