Sensing of Bacterial Adhesion on Micro- and Nanostructured Surfaces

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This tutorial examines cutting-edge micro- and nanostructured strategies to detect and prevent bacterial adhesion. Bacterial infections—driven by virtually universal surface affinity and rising nosocomial rates—pose a growing threat to global health, as biofilms readily form in moist environments like wounds and the urinary tract. On invasive medical devices, *i.e.*, long-term implants (*e.g.*, prostheses, pacemakers) and indwelling devices (*e.g.*, cardiovascular cannulas, endotracheal tubes, and urinary catheters), biofilm development often necessitates painful, costly replacement or surgical intervention [1].

We begin by critiquing current biofilm diagnostics—namely invasive sampling, lengthy culture times, and expensive molecular assays—and then introduce real-time, *in situ* electrochemical methods (amperometry, voltammetry, and impedance spectroscopy) for rapid, non-destructive infection monitoring. We also weigh the advantages and limitations of potentiometric, wireless sensing of bacterial adhesion (Fig. 1a and 1b) [2].

Next, we introduce nanoimprint lithography—a low-cost, versatile micro/nanofabrication method ideal for high-throughput manufacturing [3]. It enables patterning of any kind of material in a desired layout—even on sharp edges and curved surfaces—which gives it an advantage over traditional techniques, especially in biomedical applications requiring ergonomic, flexible designs (Fig. 1c).

Then we contrast conventional chemical coatings—including polymers, metal ions, antibiotics, and peptides, which often suffer from cytotoxicity, instability, and uncontrolled release—with bioinspired mechano-bactericidal surfaces (Fig. 1d). Precision-engineered nano-textures provide durable, drug-free anti-biofouling performance, offering a scalable, proactive solution for infection control in indwelling medical devices, especially urinary catheters that remain in place for just days or weeks.

The tutorial's centerpiece is a dual-function catheter insert: high-resolution, "cicada–wing–inspired" nanopatterns imprinted on biocompatible polyurethane to mechanically rupture *E. coli* membranes, combined with miniaturized gold/Ag | AgCl electrodes for potentiometric, Bluetooth-enabled wireless detection of early biofilm formation in human urine (Fig. 1e and 1f).

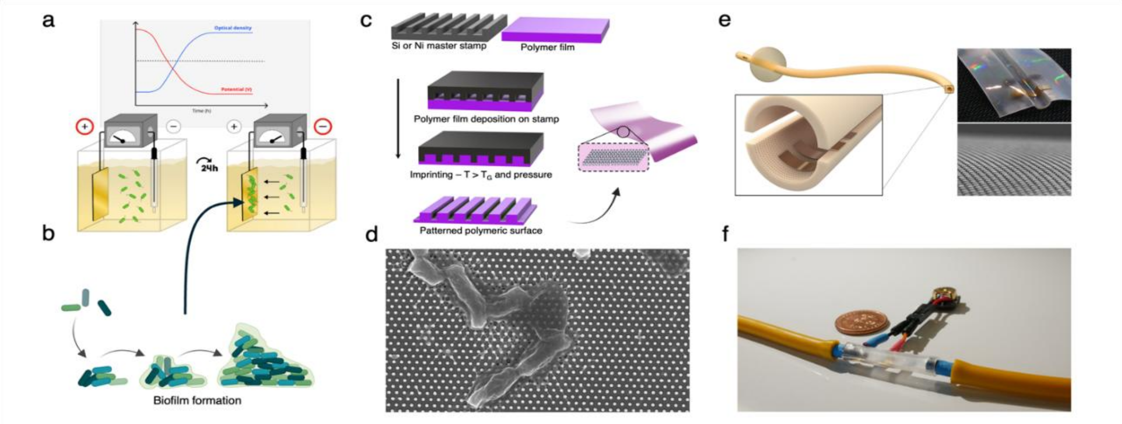

Figure 1. Development and integration of an antimicrobial, biofilm-sensing catheter insert.

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