Preventing bacterial surface contamination via mathematical modelling

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The context

Dense surface-associated colonies of bacteria known as biofilms damage safety and efficacy across industries

Healthcare

Biofilms on implanted medical devices cause almost 50% of healthcare-acquired infections

Biofilms also promote antibiotic resistance making infections hard to treat

NHS spends **£1bn/yr**

Wastewater management

Unwanted biofilms on tank surfaces reduce efficacy of water treatment

UK businesses spend **£1bn/yr**

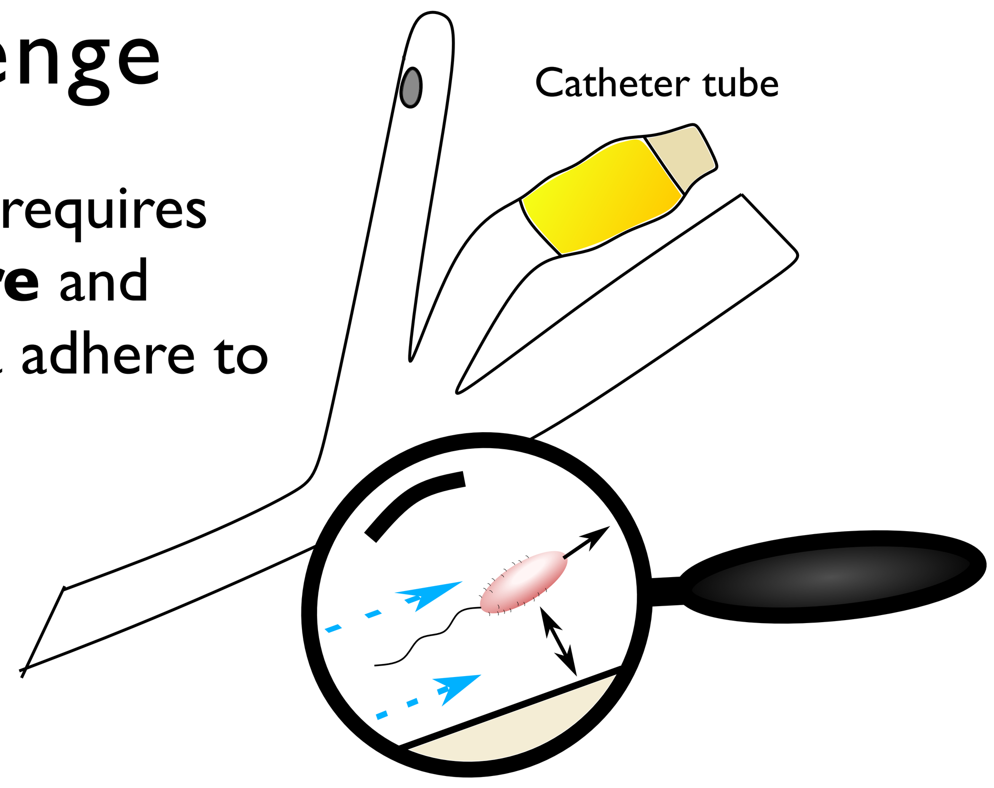
Food processing

Biofilms on tank surfaces and pipes lead to fouling of food products

Global cost of **$10.2bn/yr**

The challenge

Biofilm prevention requires predicting **where** and **how many** bacteria adhere to surfaces

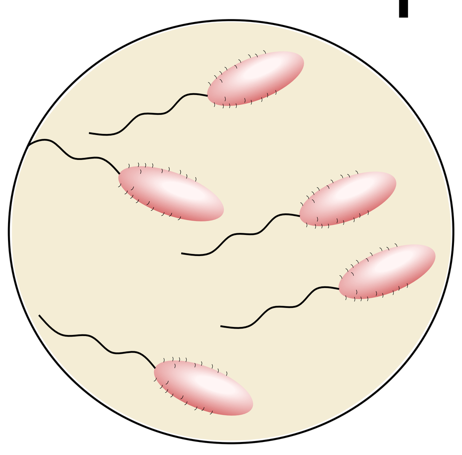


- Bacterial adhesion depends on the **complex interaction** of the fluid flow, surface chemistry & bacteria characteristics
- Bacteria exhibit **different behaviour** close to surfaces
- Tracking each bacteria is not feasible: e.g. 1ml of healthy urine contains 10,000 individual *E. coli* bacteria
- Current state-of-the-art mathematical models to predict bacterial density are **extremely computationally costly** to use.

Our method: a computationally efficient virtual exploration of bacterial adhesion

Inputs

1. Bacteria characteristics



2. Flow behaviour

3. Device dimensions

Include

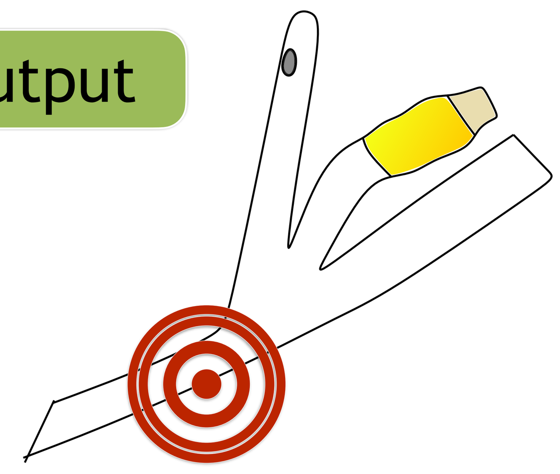
Mathematical model

- New mathematical model exploits physics of swimming bacteria in fast-flowing systems
- Systematically identifies key effects **eliminating complexity while maintaining accuracy**
- We apply mathematical **boundary layer theory**
- Further mathematical analysis gives **simple formula** for adhesion valid in certain flow regimes

$$\nabla \cdot (\mathbf{u}\rho) - D_{eff} \nabla^2 \rho = 0$$

Predict

Output



Our **boundary layer theory** can virtually predict:

1. **Where** bacteria will stick
2. The **maximum amount** of bacteria will stick at that location per second

Case study: *E. coli* in medical and industrial settings

Input bacteria and flow parameters

↓

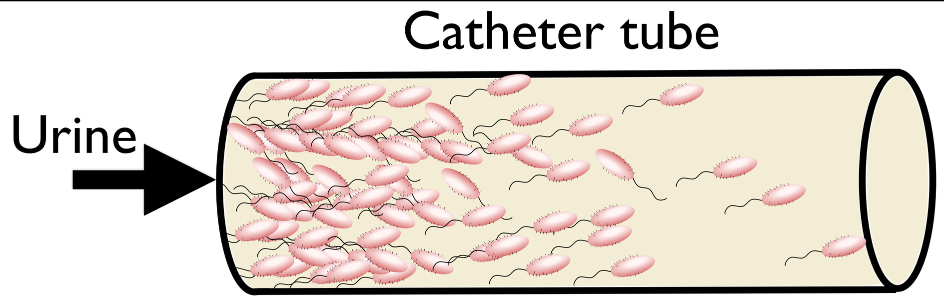
Is **boundary layer theory** valid? — No → Complex model required

Yes ↓

Does **simple formula** apply? — No → **Boundary layer theory** can be solved cheaply

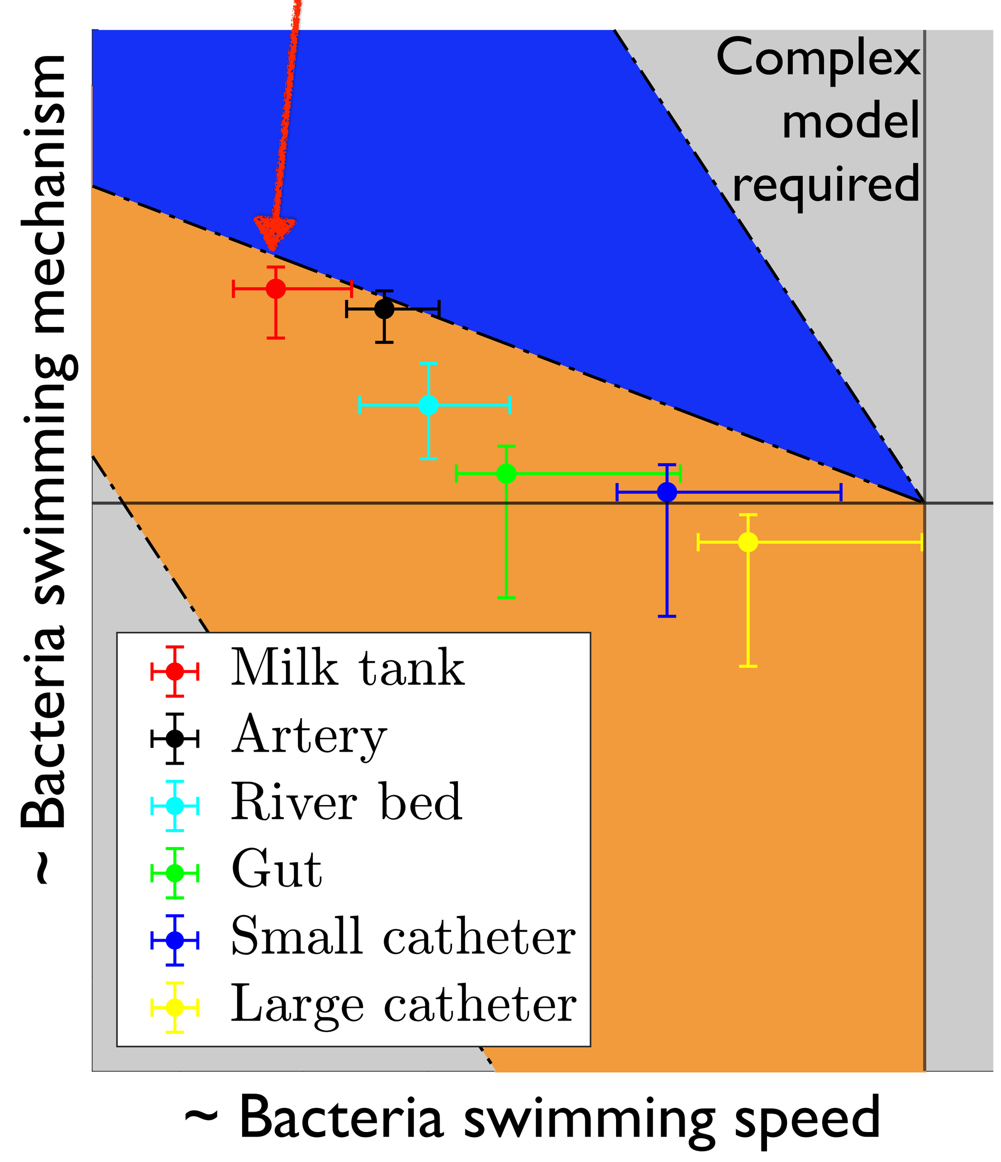
Yes ↓

Output: *E. coli* adhesion in these settings can be instantly predicted by **simple formula**



- Most adhesion at catheter inflow
- Adhesion rate increases if flow rate is higher
- Larger catheters sizes decrease adhesion

Data location tells you whether **boundary layer theory** or **simple formula** are valid



Advantages/Impact

- ☑ Our **boundary layer theory** is at least **6 times faster** at predicting bacterial density than existing complex mathematical models
- ☑ For certain systems **simple formula** can predict adhesion **instantly**
- ☑ **Minimal data needed** to predict adhesion
- ☑ **Applicable to many pathogens** relevant in industrial settings
- ☑ Predictions can be used to design new **antimicrobial devices**

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