Next-Generation Biosensing Technologies for the Detection of Infectious Agents

Fabio Di Francesco[1,2]
Angela Gilda Carota[2], G Maroli[3], Andrea Bonini[4], Marianna Rossetti[3], Noemi Poma[5], Massimo Urban[3], Giulio Rosati[3], Federico Vivaldi[1], Arianna Tavanti[5], Arben Merkoçi[2]
[1]*Department of Chemistry and Industrial Chemistry, University of Pisa, via G. Moruzzi 13, 56124 Pisa, Italy*
[2] *Institute of Electronics, Computer and Telecommunication Engineering, National Research Council, Via G. Moruzzi 3, 56124 Pisa, Italy*
[3]*Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Campus UAB, Bellaterra, 08193 Barcelona, Spain*
[4] *Dipartimento di Chimica "Ugo Schiff", University of Florence, Via della Lastruccia, 3 50019 Sesto Fiorentino (FI) Italy.*
[5] *Department of Biology, University of Pisa, via San Zeno 37, 56127 Pisa, Italy*
fabio.difrancesco@unipi.it

The rapid and accurate detection of infectious agents is essential for effective disease management, outbreak control, and global health security. Traditional diagnostic methods, while highly sensitive, often require centralized laboratories, trained personnel, and complex equipment—limitations that hinder their accessibility in low-resource settings and delay timely interventions. In this context, biosensors have emerged as transformative tools, offering decentralized, cost-effective, and real-time solutions for pathogen detection at the point of need.

Among the available biosensing strategies, CRISPR/Cas systems have gained attention for their high specificity and programmability in nucleic acid detection [1]. The CRISPR/Cas system operates as a nucleic acid-based adaptive immune system, providing defence for archaea and bacteria against bacteriophage infections, as it prevents the replication of the invader nucleic acid.

Here, the Cas12a enzyme is employed for target recognition, with its collateral cleavage activity transduced via electrochemical signal strategies relying on methylene blue-labeled DNA probes immobilized on inkjet-printed gold electrodes [2]. To enhance sensitivity and operational simplicity, the platform combines isothermal amplification (RPA), integrated heating, and a freeze-dried CRISPR complex for long-term stability. The entire system is designed for smartphone-based data acquisition via NFC, facilitating ease of use in field or clinical settings.

The biosensor successfully detected femtomolar concentrations of bacterial DNA and discriminated between clinically relevant pathogens such as Staphylococcus aureus and Pseudomonas aeruginosa. This approach exemplifies the potential of next-generation biosensing technologies to deliver accessible, rapid, and accurate diagnostics for infectious diseases, particularly in resource-constrained environments.

References

[1] Bonini et al. J Pharm Biomed Anal 192, 113645 (2021).
[2] Carota et al. Biosens Bioelectron 258, 116340 (2024).

Figures

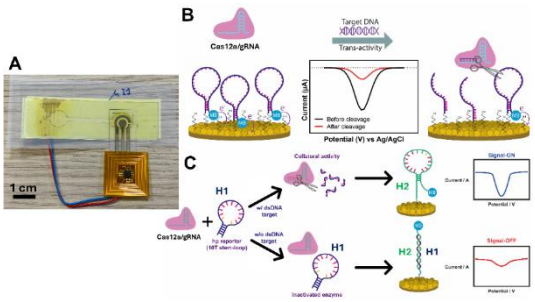

Figure 1: Sensor working mechanism.