Spiky biointerfaces – Nano-micro needle arrays for closed-loop medicine

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Scaling down the needle-and-syringe paradigm to the nano- and microscale allows us to generate nano-bio interfaces that are effective at both the cell and tissue level. Effective in terms of talking to biology, and 'writing' information into cells (delivery of genes to manipulate cell function) and 'reading' information at the tissue level (sampling biomarkers).

This 'write' talk first describes the development of arrays of nanoneedles—high-aspect-ratio silicon structures designed for gene delivery into living cells. These nanoneedles interface with cell membranes with minimal invasiveness, allowing for the direct and efficient transfer of genetic material. This approach offers a promising alternative to viral vectors, reducing immunogenic risks and enabling precise control over transfection. The nanoneedles have demonstrated success in delivering nucleic acids and CRISPR components, opening new avenues for gene therapy and regenerative medicine. Where this technology enables CAR-T generation and transfection of iPSCs.

Complementing this work with shared engineering principles but at a larger scale, in the 'read' part, we present the design of microneedle arrays for wearable biosensing. These minimally invasive devices explore (porous) silicon or fenestrated polymeric core-shell microneedles to monitor biomarkers in interstitial fluid. Designed for real-time health tracking, these biosensors can detect glucose, lactate, and other analytes such as hormones with high sensitivity and specificity, and remarkable resistance to mechanical stresses and biofouling. Their biocompatibility and mechanical robustness make them ideal for long-term wear, supporting applications in chronic disease management and personalised medicine. Finally, closed loop medicine can be achieved when the 'write' and 'read' converge, for example via on-demand drug delivery from microneedle arrays.

References:

1. R. Elnathan et al., *Nature Reviews Materials*, 7 (2022), 953–973.
2. H. Alhmoud, et al., *Progress in Materials Scien*ce, 116, (2021), 100636.
3. Y. Chen, et al., *Small*, 15 (2019), 1904819.
4. Y. Chen, et al., *Advanced Materials*, 32 (2020), 2000036.
5. Y. Chen, et al., *Materials Today* 63 (2023), 8-17.
6. J. Harberts, et al., *Advanced Materials*, 38 (2026), e21046.
7. M. Dervisevic, et al., *Nano Today* 30 (2020) 100828.
8. M. Dervisevic, et al., *Advanced Functional Materials* 32 (2022) 200985.
9. M. Dervisevic, et al., *Biosensors and Bioelectronics* 222 (2023) 114955.
9. M. Dervisevic, et al., *Advanced Materials*, 36 (2024), 2412999.
10. Y. Lin, et al., *Advanced Functional Materials*, 36 (2026,) e17918.