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From Antimicrobial Defence to Regenerative Healing: Adaptive Biointerfaces for Immune-Intelligent Nanomedicine

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The next frontier in nanomedicine lies in designing *adaptive biointerfaces* that do more than simply prevent infection—they actively orchestrate the dialogue between materials, microbes, and the immune system to restore tissue homeostasis. Traditional antimicrobial surfaces operate through static killing mechanisms that often damage host cells and fail to promote regenerative repair. In contrast, the emerging class of dynamic nano-biointerfaces embraces biological complexity, enabling materials to sense, respond, and adapt to their microenvironment.

This presentation introduces a unified framework integrating antimicrobial defence, immune modulation, and regenerative nanomedicine through two exemplar platforms. The first involves *gallium-rich liquid metal (LM) multiphase nanocoatings*, whose redox-active and self-restructuring nature enables selective, spatiotemporal control over microbial and cellular interactions. By disrupting bacterial iron metabolism and biofilm organisation while simultaneously guiding fibroblast and osteoblast adhesion, proliferation, and cytokine regulation, these LM coatings redefine the concept of antimicrobial surfaces as *immune-regenerative modulators*.

The second platform leverages *plasma-activated microalgal nano-biofilms*, where non-thermal plasma fragmentation and re-assembly of algal biopolymers create antioxidant- and peptide-rich nanolayers. These nanostructures mediate redox balance, macrophage polarization, angiogenesis, and epithelial closure—yielding a bioactive, immuno-compatible coating ideal for chronic and diabetic wound healing.

Together, these adaptive interfaces represent a paradigm shift toward *immune-intelligent materials* that bridge infection control with functional tissue regeneration. Beyond medical coatings, this framework lays the foundation for next-generation nanomedicine—where implants, scaffolds, and therapeutic surfaces operate as *living systems*, dynamically coordinating biological repair rather than passively resisting failure.